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Sustaining U.S. Nuclear Submarine Design Capabilities

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Prepared for the United States Navy

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Preface

For the first time, the U.S. Navy faces a period that could last a number of years in which there will be no design program under way for a new class of nuclear-powered submarines. The resulting lack of demand for the services of submarine designers and engineers raises concerns that this highly specialized capability could atrophy, burdening the next submarine design effort with extra costs, delays, and risks.

In 2005, the Program Executive Office (PEO) for Submarines asked the RAND Corporation to evaluate the cost and schedule impacts of various strategies for managing submarine design resources. Of concern were the design resources at Electric Boat and at Northrop Grumman Newport News (the two shipyards that have previously designed classes of nuclear submarines), as well as design resources at the key vendors that provide components for nuclear submarines and the technical resources of the various Navy organizations that oversee and participate in nuclear submarine design programs. RAND's analysis built upon similar research RAND conducted for the United Kingdom's Ministry of Defence.[1] This report documents the methods and findings of the research that RAND carried out for PEO Submarines.

[1] John F. Schank, Jessie Riposo, John Birkler, and James Chiesa, *The United Kingdom's Nuclear Submarine Industrial Base, Volume 1: Sustaining Design and Production Resources*, Santa Monica, Calif.: RAND Corporation, MG-326/1-MOD, 2005; and John F. Schank, Cynthia R. Cook, Robert Murphy, James Chiesa, Hans Pung, and John Birkler, *The United Kingdom's Nuclear Submarine Industrial Base, Volume 2: Ministry of Defence Roles and Required Technical Resources*, Santa Monica, Calif.: RAND Corporation, MG-326/2-MOD, 2005.

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Contents

Figures

Tables

Summary

For the first time since the advent of the nuclear-powered submarine, no new submarine design is under way or about to get under way following the winding down of the current effort (for the *Virginia* class, now in production). This is a matter of some concern, because submarine design is a large and complex undertaking that requires skills developed over many years that are not readily exercised in other domains. The erosion of the submarine design base—at Electric Boat (EB) and Northrop Grumman Newport News (NGNN), the two shipyards that perform the majority of a new submarine design, at the suppliers to the shipyards, and at the Navy itself—may lead to the loss of the required skills before a new design does get under way, perhaps in another six to eight years. This skill loss could result in schedule delays to allow for retraining, with consequent higher program costs and potential risks to system performance and safety. This raises the question of whether some action should be taken to sustain a portion of the design workforce over the gap in demand.

In view of these potential problems and the postulated solution, we sought to answer the following questions:

- How much of the submarine design workforce at the shipyards would need to be sustained for the least-cost transition to the next design? What are the implications of different approaches to allocating the workload?
- To what extent is the shipyard supplier base also at risk?
- How will the Navy's own design skills be affected by a gap, and how easily might they be recovered?

- Taking all answers to the preceding questions into account, what steps should the Navy take in the near future?

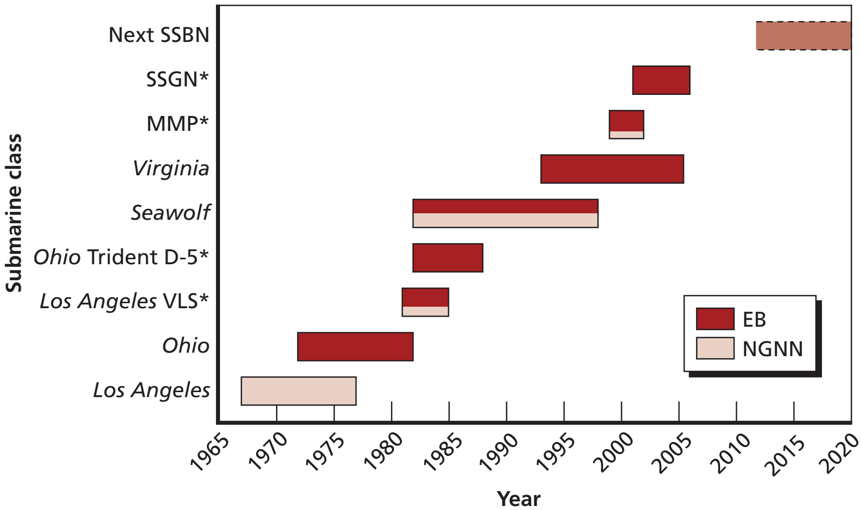
We take up each of these questions in order below. First, however, by way of background, we give a brief overview of the submarine design process and describe our approach to analyzing the problem at the shipyards (which has implications for the other design resources).

The Submarine Design Process

The early years of nuclear submarine design were marked by experimentation. A new design was undertaken even before work had finished on the previous one, and few boats were built to the same design. As the Navy and the builders gained experience and winnowed the spectrum of alternative approaches to submarine design, some stability was achieved. The *Sturgeon* class, the first of which was commissioned in 1966, extended to 37 boats. Still, the evolution of the Soviet threat required the introduction of new designs in response (see Figure S.1). The *Los Angeles* class was introduced to service in 1976 and went through two additional "flights," or significant design updates, over the next 20 years. In the post–Cold War era, changes in the threat are still recognized in submarine design: Some ballistic-missile-carrying boats of the *Ohio* class have been partially redesigned to carry guided missiles, and more attention is being paid to submarines' special-forces transport and support function. New designs, though, are largely being driven by the need to replace older boats that are wearing out. At present no such need exists, and for the first time since the advent of nuclear power, no new submarine design is on the drawing board, and, according to current Navy plans, none will be for several years.

Submarine design is currently broken down into a set of "product areas"—requirements, arrangement, mock-up, etc.—which are somewhat like work phases but which are allowed some temporal overlap. This overlapping sequence of product areas is developed for each of eight "modules"—habitability, propulsion, sail, etc. Clearly, there is a need for designers and engineers skilled in areas that do not always replicate those common to other ships. In addition, experience peculiar

Figure S.1
Overlapping U.S. Submarine Design Efforts Are Giving Way to a Gap in Demand



*Major modification to an exsiting class.
RAND *MG608-S.1*

to submarine design must be applied to ensure that all modules will be integrated appropriately.

For the purpose of our analysis, we categorized these skills in a hierarchy. Following industry analyses, we group the hundreds of skills necessary to design a nuclear submarine into 16 skill categories.

Framing the Analysis

To understand submarine design demand and supply relationships and the costs and benefits of different approaches to managing the design workforce, we categorize the available choices into two broad approaches—"doing nothing" and "doing something." Under the first approach, the prime contractors would adjust their workforce to meet known demands only. In the second, they would sustain a number of designers and engineers above known demands to serve as a foundation to rebuild the workforce for a new design effort.

The first step in analyzing the two approaches is to predict the demand for the next submarine design and its timing. We start with

the known demands—the design work "on the books" that involves both support to construction efforts on in-service submarines and to any new design efforts for surface ships, such as the CVN 78 class of aircraft carriers, or for major modifications to the *Virginia* class. We then estimate when a new design effort might begin, how long it would take, and the magnitude of the workload demand. Using the current 30-year shipbuilding plan as a guide and assuming the next design effort would be similar to that of the *Virginia* class, our baseline case assumes the start of a new nuclear-powered ballistic-missile submarine (SSBN) design in 2014 that will last 15 years and require approximately 35 million man-hours of design and engineering effort. Because of the uncertainties in such a projection, we examine the sensitivity of our results to different start dates, durations, and workloads.[2]

The 2014 design start date has the virtue that the SSBN design effort will wind down about the time the design of a replacement for the *Virginia* class will be ramping up. Such a long-term view should be part of the submarine acquisition planning process, because a skilled workforce must be managed with the long view in mind. If the SSBN design were delayed by four or five years, it would overlap too much with the next nuclear-powered attack submarine (SSN) design. If it started much earlier than 2014, the current gap in demand could be replaced by a gap following the SSBN design.

Given a predicted demand, the next step in the analysis is to estimate how much the different "do-nothing" and "do-something" strategies will cost. Costs for different workforce drawdown and buildup profiles vary because of termination costs and hiring and training costs. There could also be delays associated with a less efficient workforce. This all adds up to different workload-accomplishment efficiencies for different labor supply profiles. RAND has previously quantified the costs of production gaps; however, that research was focused on production workers. For design workers, we would expect, on the one hand, lower penalties from lost learning because there is an inherent novelty to each succeeding design effort, but on the other hand, higher

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[2] Note there is a unique "do-nothing" case for each combination of start date, design workload, design duration, and shipyard.

penalties for the potential loss of expertise, which should take longer to accumulate for design than for production. Productivity losses, along with training, other hiring, and termination costs, are all estimated in a workforce simulation model that we developed. Both shipyards provided data for estimating these productivity losses and costs.

The following caveats apply to the results of our analysis:

- Our model does not produce budget-quality cost estimates.
- All costs are estimates subject to estimating errors associated with future uncertainties.
- Workforce-related model inputs are based on data received from EB and NGNN.
- We assumed that both shipyards currently have the critical skills and proficiency necessary for submarine design.

Impact of Different Policies for Managing Design Resources

The model indicates that, if the next SSBN is designed at EB and the "do nothing" approach is adopted, the design effort will take about three years longer than our nominal assumption of 15 years. Sustaining a workforce above the level needed to meet demand would cut back the increase in design duration. If 800 extra people could be sustained, there would be no increase. Those extra people cost money, but they also save money by precluding the extra work associated with the schedule delay and with workforce transition costs (termination, hiring, and training). The net cost is least when 800 people are sustained: That cost is about 10 percent less than what the "do nothing" approach would cost. Doing the same analysis for NGNN indicates that 1,050 designers and engineers should be sustained and that doing so would save 36 percent relative to the "do nothing" design cost.

The least-cost workforce to sustain is relatively insensitive to the start date but somewhat more sensitive to the total workload (see Table S.1). If the latter were to be 30 percent higher or lower than that for the *Virginia* class, the least expensive workforce would increase or decrease responsively—by 20 to 30 percent for most start dates at EB or NGNN. At the *Virginia*-class workload, the total cost would increase with later start dates (longer gaps) and decrease with earlier dates. The percentage

saved relative to the "do nothing" approach would also be higher with higher workloads and later start dates and lower with lower workloads and earlier dates. At the expected 2014 start date, however, the sensitivity of percentage savings to workload would be small. At the expected workload level, the sensitivity to start date would be large in the later half of the range at NGNN and in the early half at EB.

So far, we have been assuming that an early start date would be followed by our assumed 15-year design period. However, the design effort might be stretched to 20 years. That would have the benefit of filling the current design gap without creating another once the SSBN effort is complete. That is, the workforce sustained during the gap would be engaged in productive activity toward design of the new SSBN class. This is reflected in the savings: Stretching the design period results in an additional 17 percent savings relative to the 15-year cost at EB, and 22 percent at NGNN. For a given workload, these 20-year-design alternatives cost the least.

Table S.1
Results for Different Design Workloads and Start Dates

	Results for Workloads Ranging from 30% Below to 30% Above *Virginia*-Class Design Workload, for Start Dates of		
	2009	2014	2018
EB			
Minimum-cost workforce to sustain	800–1,150	550–1,000	550–1,000
Labor cost savings relative to "doing nothing" (%)	0–14	10–14	28–31
NGNN			
Minimum-cost workforce to sustain	850–1,400	700–1,200	700–1,200
Labor cost savings relative to "doing nothing" (%)	2–17	37–42	41–46

NOTE: All savings are relative to doing nothing prior to the start date assumed and for the workload assumed.

The Navy might consider it advantageous to split the design work between EB and NGNN rather than retain design expertise at only one firm. If the work is evenly split between EB and NGNN, the cost is a little higher than doing the work at one yard, even without taking into account any of the inefficiencies involved in sharing the work. A 25 percent penalty for such inefficiencies might not be an unreasonable estimate, and the cost would increase accordingly.

Finally, optimistic and pessimistic scenarios help to test how sensitive our results would be to variations in some of the parameters associated with the workforce: productivity, attrition, and hiring rate. The optimistic scenario has higher productivity, a greater hiring rate, and lower attrition, and the pessimistic scenario varies these parameters in the opposite direction. These variations are consistent with those reported in the literature. In these alternative scenarios, the least-cost workforce sustained would vary by 150 to 200 people—higher in the pessimistic scenario and lower in the optimistic one. Costs, of course, follow. At EB, costs in the optimistic scenario would be about 5 percent below those for the 15-year design baseline, and in the pessimistic scenario, over 20 percent higher.

It is important to recognize that the less costly alternatives—sustaining a workforce in excess of demand or, preferably, extending the design period to 20 years—have nontrivial drawbacks that are not easily quantified. Sustaining a workforce in excess of demand raises the question of what the excess workers are to do to maintain their skills. There are several options available that address aspects of the problem, but even if combined and coordinated with other activities, these options may not keep skilled personnel from leaving or sustain the skills of those who stay as effectively as design work on a new submarine class would. Extending the design period to 20 years raises various risks, such as increased overhead and design obsolescence by the time the first submarine of the class takes to sea. Of course, "doing nothing" risks the loss of key submarine skills.

Critical Skills

We have established the need to sustain 800 designers and engineers at EB, or 1,050 at NGNN, through the design gap if costs are to be

minimized. These numbers should include representatives from all the various skill groups, to ensure that all skills will survive a gap and that there will be an adequate base of mentors able to reconstitute those skills in the workforce. The specific number to be sustained from each skill group will depend on various factors relating to the future demand for each skill, the probability of losing each skill, and the difficulty of reconstituting it. Those factors include

- The technical specifications of the next submarine design. If there is expected to be a significant change from the current design, the distribution of skills to retain should reflect that. For example, if it is likely that the next design will use electric drive, more electrical and fewer mechanical engineers will be required.
- Workforce demographics. Skill groups with older workforces need more management attention to ensure that a critical mass is not lost. About half the planning and production workforce at NGNN and most of the engineering support workforce at EB are over 50.
- Ability to find skills outside the nuclear submarine industry. Certain skills may be exercised in nuclear submarine design only, e.g., acoustics engineers and signals analysts who specialize in silencing and structural engineers specializing in shock. If these skills are lost, reconstituting them will be more challenging than for other types of skills.
- Time to gain proficiency. Skills that take a particularly long time to develop (because they require either a great deal of formal education or occupational training time) are also more challenging to reconstitute than skills that take less time to develop. Approximately 10 percent of technical skills, for example, require 10 years of on-the-job experience to develop.
- Other supply and demand factors. These may affect the availability of certain skills or the ease with which individuals with particular skills can be attracted to industry. The number of nuclear engineering programs in U.S. universities, for example, has fallen by about half over the past 30 years. Partly as a result, the supply of workers is decreasing in certain key areas. At the same time,

the U.S. Department of Energy forecasts that new nuclear power plants will be needed by 2025, which suggests a competing demand for nuclear engineers.

Suppliers

Submarines, like other large, complex systems, are not designed by a single firm. A single firm cannot productively sustain all the special skills required. The submarine design base thus includes a large number of subcontractors that contribute design expertise or engineered components to plug into the system. How will these firms be affected by a gap in design demand?

To find out, we surveyed 58 suppliers identified by the shipbuilders as having significant activities associated with submarine design. We received responses from 38 of the 58 firms the shipbuilders identified; 32 felt that they had significant activities associated with submarine design. We analyzed these 32 responses according to a set of indicators of potential risk in the design industrial base:

- Percentage of revenue generated by design work. Only one firm got most of its revenue from design. Considered alone, this suggests that most firms could weather a design gap.
- Percentage of revenue from submarine business. Three-quarters of the firms got less than half their revenue from the submarine business—another indicator that a design gap would not have a large impact.
- Absence of competitors. Only five firms believed they had no competitors, suggesting that in the event some suppliers fail, the shipbuilder will typically have alternatives.
- Insufficient design workforce supply. Most suppliers indicated they would not have a problem maintaining a technical workforce within the next 10 years—a period that extends through the expected SSBN design start date. About half foresee trouble beyond that, though.
- Percentage of workforce in upper age range. At over half the firms, most of the workforce is more than 45 years old. This is problematic because it suggests that many workers could approach retire-

ment over the course of a submarine design gap. Not only will such workers be unavailable to meet workforce demand, they will not be there to mentor younger workers.
- Time required to ramp up a design staff. Two-thirds of the firms thought that it would take a year or less to ramp up for a new submarine design effort. There appears to be little problem in that regard.
- Time required before a new hire is productive. Most respondents judged that it would take over six months for new hires to become adapted to the firm and proficient in their role.
- Extent to which employment falls short of demand peak for design. The great majority of firms indicated that they already had sufficient staff to meet the peak design demand from a new submarine program.

The survey results suggest some reason for concern. In their comments to us, suppliers were generally concerned over the lack of demand for submarine design in the near term. Furthermore, while we cite various favorable majorities, for all the indicators some firms show a degree of risk. Eight firms exhibited risk in more than one category.

There are several possible options available for addressing supplier risk. One is to stretch the submarine design (e.g., to 20 years) to provide some near-term work and cut down the variability of demand. Spiral development of the *Virginia* class could also provide work for some suppliers. Other risk reduction measures would seek to compensate for the loss of a supplier. For some inputs, an alternative supplier could be sought. For others, the technology the vendor supplies might be replaced by some newer (or older) technology or the current design might be retained.

Most of these options are not applicable to all suppliers, as the situations of the different firms vary. In particular, stretching the design duration, a promising option for addressing the design gap at the shipyard, will not work for most of the vendors. The choice of intervention, or mix of interventions, will have to be tailored to each vendor at risk.

Navy Roles and Responsibilities

The Navy is ultimately responsible for a safe, effective, and affordable submarine design. In carrying out this responsibility, the Navy fulfills three roles: It provides technical infrastructure and expertise, it designs and develops certain critical components, and it supports submarine-related science and technology.

In providing technical infrastructure and expertise, the Navy plays the role of smart buyer. That is, it must ensure that the design efficiently meets Navy program requirements. In this capacity, for example, the Navy implemented integrated process and product development in the design of the *Virginia* class, an innovation intended to save time and money by making Navy design reviews a part of the ongoing effort rather than a milestone occurrence. Another aspect of the infrastructure and expertise provided by the Navy is its role as the technical authority. This role is taken on specifically by an array of technical warrant holders, each of whom certifies within his or her area of expertise that the design is safe, technically feasible, and affordable. Finally, the Navy is responsible for design-phase testing and evaluation.

The Navy retains sole responsibility for designing and developing components that are associated with the nuclear propulsion plant, critical to submarine safety, critical to the integration and interoperability of the command-and-communication and combat-control systems, or not commercially viable for private industry to design. Submarine-related science and technology is integrated through the Submarine Technology (SUBTECH) program, which consists of integrated product teams focusing on communications, weapon systems, self-defense, and hull and propulsion issues.

One of the strengths of the Navy's acquisition process is the separation of the responsibility for managing acquisition programs from the technical approval process. Program managers are responsible for program performance in cost and schedule terms. The Navy's technical establishment is responsible for the technical acceptability of the product design. In this way, safety issues are not subject to trade-offs against costs or schedule concerns.

The Navy's design resources are physically and organizationally dispersed between the headquarters of the Naval Sea Systems Com-

mand (NAVSEA) and its naval warfare centers. NAVSEA engineers oversee the design, construction, and support of the Navy's fleet of ships, submarines, and combat systems. The naval warfare centers are charged with carrying out many of the specific activities supporting the Navy's design responsibilities, described above. The Naval Surface Warfare Center (NSWC) is responsible for hull, mechanical, and electrical (HM&E) systems and propulsors for both surface and undersea vessels. The Naval Undersea Warfare Center (NUWC) is responsible for submarine weapons and combat systems.

The current division of responsibilities between NAVSEA and the warfare centers reflects a transition from a state in which more people were housed within NAVSEA. A major purpose of that transition was to move staffing from mission-funded positions, billable to Navy overhead, to program-funded positions, billable to a PEO. The warfare centers operate more like private contractors, billing their time to specific accounts and moving personnel to wherever the work is needed. This has obvious implications for the conservation of submarine design expertise in the Navy.

Impact of a Design Gap on the Navy

As with the shipyards, a design gap could affect the Navy through personnel termination, consequent skill loss, impediments to the development of managers, and eventual hiring and training, or rehiring and retraining, with all the costs those involve. There is also the possibility that some skills, once lost, could be difficult to regain.

The effects of a gap would vary by organization. As a mission-funded organization, NAVSEA's technical infrastructure would likely survive a submarine design gap. However, the ability to perform certain technical oversight functions could degrade without the opportunity to exercise those functions. Whole-ship integration skills could be particularly affected. The lack of relevant work could also retard the development of proficient senior managers in the submarine design area.

The impact of a design gap on the naval warfare centers depends on the technical areas involved. Non-HM&E areas are relatively insensitive to the gap, because this work is performed at NUWC, where in-

service modernization programs make up the bulk of program funding and provide a healthy technical basis for new submarine design. However, at NSWC's Carderock Division, ongoing in-service submarine support, technical assistance to the *Virginia*-class production program, and science and technology programs will not support the skills required for a full submarine design effort. As a result, engineers and designers who have been working on the *Virginia* design will shift to funded programs (i.e., those unrelated to submarines) or leave. Keeping some of these people working on tasks more relevant to submarine design—that is, maintaining a core submarine design group of personnel and facilities—would require an additional $30 million to $35 million per year of funding for Carderock during the design gap.

Here, as in the case of the shipyards, stretching the design duration from 15 to 20 years would allow an early start and avoidance of the design gap. Costs and proficiency losses would thus be avoided.

Recommendations

From the preceding analysis, we reach the following recommendations:

- Seriously consider starting the design of the next submarine class by 2009, to run 20 years, taking into account the substantial advantages and disadvantages involved.

If the 20-year-design alternative survives further evaluation, the issue of a gap in submarine design is resolved, and no further actions need be taken. If that alternative is judged too risky, we recommend the following:

- Thoroughly and critically evaluate the degree to which options such as the spiral development of the *Virginia* class or design without construction will be able to substitute for new-submarine design in allowing design professionals to retain their skills.

If options to sustain design personnel in excess of demand are judged on balance to offer clear advantages over letting the workforce erode, then the Navy should take the following actions:

- Request sufficient funding to sustain excess design workforces at the shipyards large enough to permit substantial savings in time and money later.
- Taking into account trends affecting the evolution of critical skills, continue efforts to determine which shipyard skills need action to preserve them within the sustained design core.
- Conduct a comprehensive analysis of vendors to the shipyards to determine which require intervention to preserve critical skills.
- Invest $30 million to $35 million annually in the NSWC's Carderock Division submarine design workforce in excess of reimbursable demand to sustain skills that might otherwise be lost.

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Abbreviations

C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CAD/CAM	computer-assisted design/computer-aided manufacturing
CEM	cost engineering manager
CHENG	chief engineer
COTS	commercial off the shelf
CSE	chief systems engineer
CVN	carrier vessel, nuclear
DDG	destroyer, guided missile
DoD	Department of Defense
EB	Electric Boat
HM&E	hull, mechanical, and electrical
IPPD	integrated product and process development
IPT	integrated product team

MAT	major area team
MMP	multimission platform
NAVSEA	Naval Sea Systems Command
NGNN	Northrop Grumman Newport News
NPV	net present value
NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
PAD	product area director
PEO	program executive office
S&T	science and technology
SDM	ship design manager
SSBN	ship submersible ballistic, nuclear
SSGN	ship submersible guided, nuclear
SSN	ship submersible, nuclear
SUBTECH	Submarine Technology program
TAE	technical area expert
TPO	technical process owner
UK	United Kingdom
USW	undersea warfare
VLS	Vertical Launch System

CHAPTER ONE

Introduction

Problem and Objectives

Since the commissioning of the USS *Nautilus* in 1954, the U.S. Navy has aimed to maintain technical superiority over all other countries' submarine forces. The U.S. submarine fleet currently numbers over 50 fast attack submarines (SSNs) and 18 submarines built to launch ballistic missiles (SSBNs), four of which (SSGNs) are or have been converted to launch cruise missiles. All are nuclear powered to maximize the duration and speed of underwater operations.[1] While the submarine fleet has been decreasing in number since the end of the Cold War, it is anticipated that the U.S. Navy will sustain a force of several dozen boats into the foreseeable future. The SSBNs are a key element of the U.S. strategic nuclear deterrent, and SSNs have demonstrated their flexibility in the face of evolving threats. Originally intended for various Cold War missions, such as protecting sea-lanes against enemy submarines and other combatants, SSNs have been used in the post–9/11 era for the insertion of special-operations forces, reconnaissance, and strikes against land targets.

To realize efficiencies in production, submarines, like other U.S. warships, are bought in fairly large quantities over long production runs. For example, the Navy plans to buy the current *Virginia* class

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[1] The Navy also operates some small submersibles. In this report, we use the term *submarine* only in reference to SSNs, SSGNs, and SSBNs.

of SSNs for twenty years or more. Although, like anything else, submarines wear out, recent improvements in materiel and processes have increased the operational life of the *Virginia* class to 33 years and of the *Ohio* SSBN class to potentially 45 years. As a result, the start of the design effort for a new class of submarines could be a decade or more away.

Designing a new class of nuclear submarines is a very large and complex endeavor, lasting 15 years or longer and requiring 15,000 to 20,000 man-years at a prime contractor, either Electric Boat (EB) or Northrop Grumman Newport News (NGNN). Other applied scientists and engineers work for the Navy in technology development, in the design of certain critical components, and in the role of ultimate technical authority for ensuring safety and determining the appropriate tradeoffs among performance, schedule, and cost. But it is not just the size of the effort that is noteworthy. Submarine engineers and designers must possess special skills beyond those required for building most other kinds of warships. The hull and other ship systems must be able to resist the physical pressure of undersea operations. Many systems must be designed for greater compactness and quietness than is needed on surface vessels. Finally, there is the nuclear propulsion plant, which must be a model of miniaturization while operating safely in the immediate vicinity of the ship's crew.

Moreover, it is not just the engineers and designers at the prime contractor shipyards and in the Navy that must be considered. In addition, there is a large vendor base consisting of over a thousand subcontractors, all of whom employ numerous skilled professionals to carry out the detailed design of major and minor systems and components. A number of these systems and components are to some degree distinctive in their applications in submarines.[2] There are also test facilities and other physical plant elements that must be maintained in order to avoid having to rebuild them.

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[2] John Birkler, John Schank, Giles Smith, Fred Timson, James Chiesa, Marc Goldberg, Michael Mattock, and Malcolm MacKinnon, *The U.S. Submarine Production Base: An Analysis of Cost, Schedule, and Risk for Selected Force Structures,* Santa Monica, Calif.: RAND Corporation, MR-456-OSD, 1994, p. 59

These submarine-specific engineering and design skills cannot be regenerated from scratch every time a new submarine class is needed. That would take too long, cost too much, and subject the project to the risk of failure. Until now, the drawdown and reconstitution of the nuclear submarine design force has not been an issue—it has never occurred. With the potential of a long gap before the start of the next new submarine design program, several issues arise as to how best to manage the critical skills required for submarine design to ensure the capability is available when needed in the future.

Specifically, we seek to address the following issues:

- How much of the submarine design workforce at the shipyards would need to be sustained for the least-cost transition to the next design? What are the implications of different approaches to allocating the workload?
- To what extent is the shipyard supplier base also at risk?
- How will the Navy's own design skills be affected by a gap, and how easily might they be recovered?
- Taking all of the answers to the preceding questions into account, what steps should the Navy take in the near future?

It is important that these questions are answered; the Navy must not let entropy take over and must not allow the submarine design base to erode without serious consideration of the potential consequences. The United Kingdom's (UK's) recent experience with submarine design bears on this issue.[3] Insufficient attention was paid to sustaining submarine design resources during the gap between the end of the *Van-*

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[3] For a full treatment of the UK experience, see Schank et al., *The United Kingdom's Nuclear Submarine Industrial Base, Volume 1;* and Schank et al., *The United Kingdom's Nuclear Submarine Industrial Base, Volume 2*. In another example of potential key skill degradation, the Defense Science Board examined the current and future capabilities of the U.S. industrial base to maintain, upgrade, and design replacement strategic nuclear and non-nuclear strike systems (see U.S. Department of Defense, Defense Science Board, *Report of the Defense Science Board Task Force on Future Strategic Skills*, Washington, D.C.: Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, March 2006). They concluded current capabilities in certain areas were marginal and recommended a program to sustain key skills during the gap in strategic system design efforts.

guard program in the late 1980s and the start of the *Astute* program in 1992. Also, driven principally by a desire to shift design responsibility to the private sector, the UK Ministry of Defence allowed its in-house submarine design expertise to dissipate from the late 1980s through the mid-1990s. As a result, the design of the *Astute* was beset with problems and, by 2005, the acquisition program was three years behind schedule and almost $2 billion over budget, compared to the original estimates. Although there were several reasons for this, the loss of design expertise is thought to have played an important role. Recognizing the need to sustain submarine design resources, the UK has recently announced plans to design and build a new generation of nuclear ballistic-missile submarines.[4]

Nuclear submarines are among the most complex and expensive defense systems to build. They perform in stressful physical environments, and the lives of many U.S. servicemen depend on their safe operation. These are not systems on which to experiment with an inexperienced design force. What needs to be done to keep that from happening?

Analytical Approach

Our analysis examines the designers and engineers that constitute the nuclear submarine design industrial base and how their numbers, productivity, and experience change over time under different workforce management options. We estimate the future demand for design resources, focusing on when a new design effort may begin and the number of designers and engineers a new program will require. The potential start of a new design effort is based on current planning documents and fleet demographics, and estimates of the duration and magnitude of the design effort are based on historical data. Because of future uncertainties, ranges are explored around all these estimates.

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4 See *The Future of the United Kingdom's Nuclear Deterrent*, presented to Parliament by the Secretary of State for Defence and the Secretary of State for Foreign and Commonwealth Affairs by the Command of Her Majesty, Cm 6994, December 2006.

A simulation model is used to estimate the cost and schedule implications of sustaining various numbers of designers and engineers at EB and NGNN during a gap in the demand for submarine design resources. Using data provided by the shipyards, we apply the model under varying assumptions regarding start dates, workload demands, and design durations. We consider options where all design work is given to EB or NGNN as well as options that involve spreading the work between the two organizations.

A survey instrument supported our analysis of the viability of design resources at the various vendors. Based on data received from over 30 vendors, we identify those suppliers who potentially face difficulties in sustaining their design resources, and we suggest options for supporting those vendors during a design gap.

Finally, we interviewed the various Navy organizations that support new submarine design efforts and gathered various data on their future demands and current resource levels. Using these data, we identify the Navy organizations that face potential workforce problems.

Organization of This Monograph

Chapter Two provides an overview of the submarine design process and how it has evolved over the last two decades. It also describes the skill categories used in our analysis. Chapter Three describes our analytical methodology, including how we estimate the future demand for submarine design resources and the simulation model we developed to understand the cost and schedule implications of different workforce management options. Chapter Four presents the results of our analysis of sustaining design resources at EB and NGNN; it describes the least-cost number of designers and engineers to sustain during the design gap under various assumptions on the timing, duration, and magnitude of the next new submarine design effort. Chapter Five discusses the various factors that must be considered when deciding how the cost-effective number of designers and engineers to sustain is distributed across the various skill categories.

Chapter Six describes our analysis of design resources at the vendors. It summarizes the data that we received from the vendors and describes our approach for identifying vendors that potentially face a high risk of being unable to sustain their critical design capabilities. Chapter Seven describes the roles and responsibilities of various Navy organizations during the submarine design process and how technical resources are currently distributed within the Navy. Chapter Eight presents our analysis of the viability of Navy design resources during a gap in new design efforts. Finally, Chapter Nine summarizes our analysis and provides findings and recommendations.

CHAPTER TWO

The Submarine Design Process

The design and engineering[1] of any complex system requires special skills, tools, and experience. Of all naval combatants, a nuclear-powered submarine presents the greatest design challenge. The unique operating environment and characteristics of a nuclear submarine impose special demands on designers and engineers. These individuals need special skills to address the ability to operate in three dimensions, the requirement to submerge and surface, the fine degree of system integration necessary due to weight and volume limitations, and the use of nuclear propulsion. Many of these skills are not found or maintained in the design of other U.S. naval ships.

In this chapter, we describe the nuclear submarine design process and how it has evolved over the past five decades. We also describe the range of different skills and technical competencies required for the design of a new submarine and how we organized the various technical skills into competency groups for our analysis. We begin with a brief overview of the evolution of submarine designs in the U.S. Navy.

[1] By *design*, we mean the creative activity encompassing naval architecture and all aspects of marine engineering necessary to produce a new concept or design a major modification to an existing one. In contrast, we use the term *engineering* to represent the application of engineering tools, methods, and principles to solve specific problems raised by the design and to provide the support for the translation of the design to production. We group these two activities together in our discussions of the design process. When we discuss the skills required for a new submarine design, designers are typically the individuals who use computer-assisted design and manufacturing software to translate the designs of engineers into a product model. Note that EB and NGNN employ designers and engineers differently.

Evolution of the Nuclear Submarine Force

The U.S. submarine fleet began to transition from diesel-electric to nuclear propulsion with the commissioning of the USS *Nautilus* (SSN-571) in 1954. At that time, the U.S. fleet consisted of 140 diesel-electric boats. Over the next ten years, further nuclear-propulsion-plant and hull-form developments characterized each new series of submarine class. In addition to SSNs, Cold War threats dictated the development of SSBNs. Table 2.1 shows the evolution of the U.S. nuclear submarine fleet over the last 50 years.

Table 2.1
Historical U.S. Navy Submarine Fleet

Submarine Class	Class Size	Commission Dates	Type of Submarine
Nautilus	1	1954	Attack
Seawolf	1	1957	Attack
Skate	4	1958–1959	Attack
Skipjack	6	1959–1961	Attack
Triton	1	1959	Attack
George Washington	5	1960–1962	Ballistic missile
Halibut	1	1960	Guided missile
Tullibee	1	1960	Attack
Thresher/Permit	14	1961–1968	Attack
Ethan Allen	5	1961–1963	Ballistic missile
Lafayette	9	1963–1964	Ballistic missile
James Madison	10	1964	Ballistic missile
Benjamin Franklin	12	1965–1967	Ballistic missile
Sturgeon	37	1966–1975	Attack
Narwhal	1	1969	Attack
Lipscomb	1	1974	Attack

Table 2.1—Continued

Submarine Class	Class Size	Commission Dates	Type of Submarine
Los Angeles	62	1976–1996	Attack
Ohio	18	1981–1997	Ballistic missile
Seawolf	3	1997–2005	Attack
Virginia	8+	2004–present	Attack

The rapidly evolving field of nuclear propulsion and its effects on available hull forms, size, and internal systems required significant experimentation. During the early days of submarine production, the design and construction of one-off submarines was commonplace. The political climate and the desire to be at the front of the arms race led to the government providing the Navy with ample resources for submarine design and production. Frequent design and production efforts were necessary as new technologies and designs were evolving and being tested. In fact, 15 of the 20 classes were first produced between 1955 and 1969.

As nuclear submarine technology evolved, the size of the submarine classes grew because the Navy gained a cost advantage from repeated construction of the same design. The early, small classes in the SSN fleet were followed by the construction of two large classes of submarines. The *Sturgeon* (SSN 637) class ultimately consisted of 37 SSNs and the *Los Angeles* (SSN 688) class extended to 62 hulls, incorporating multiple flights.[2] The current composition of the U.S. submarine fleet is shown in Table 2.2.

Each class of ships, of course, required a new design, and the succession of classes in the early years of the nuclear submarine ensured a continuous, even overlapping, series of design efforts. That was less the case once production of the *Los Angeles* class got under way, but opportunities for design work still occurred (see Figure 2.1, which also

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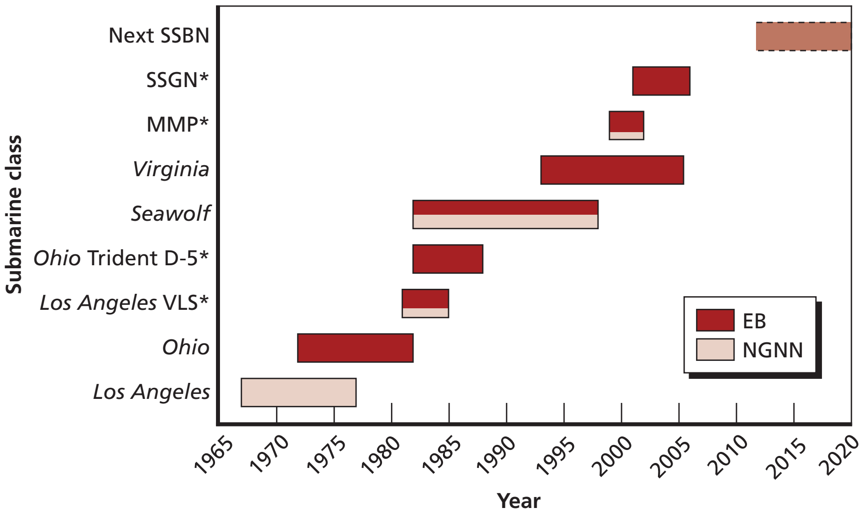
[2] A *flight* consists of a significant alteration to the baseline ship in either the propulsion plant or combat systems.

Table 2.2
U.S. Navy Submarine Fleet (2006)

Ship Class	Type	Number
Los Angeles	SSN	50
Seawolf	SSN	3
Virginia	SSN	3
Ohio	SSGN	4
Ohio	SSBN	14

Figure 2.1
U.S. Submarine Design Program Durations Since the Start of the *Los Angeles* Class



*Major modification to an exsisting class.
RAND *MG608-2.1*

indicates the allocation of design work between the two qualified shipyards). While the first 31 *Los Angeles*–class hulls experienced minor modifications, the remaining hulls incorporated 12 vertical launch tubes mounted in the forward ballast tanks and loaded with Tomahawk cruise missiles. This Vertical Launch System (VLS) required some

design work, and in the "improved" (or 688I) class the forward diving planes were moved from the sail to the bow, the sail was strengthened for ice penetration, a mine laying capability was added, and the combat systems were improved.[3] Boats of the *Los Angeles* class constitute the bulk of the U.S. submarine force today. Also, in the interim between the *Sturgeon* class and the *Ohio* class, when NGNN designed the *Los Angeles* class, EB had several designs in process, including the *Narwhal*, *Lipscomb*, and NR-1, which helped them bridge the gap.

The *Seawolf* class (SSN 21) was designed to counter the increasingly sophisticated and acoustically capable Soviet submarine threat of the 1980s. As a result, the *Seawolf* class incorporates significantly improved acoustic performance, the ability to transit and maneuver at high speeds, and a massive torpedo room (50 weapons) in a large submarine displacing over 9,000 tons. Only three *Seawolf* submarines were constructed due to their high cost and the end of the Cold War. The third *Seawolf*, *Jimmy Carter* (SSN 23), has been heavily modified to incorporate a multi-mission platform (MMP), which gives the boat a more flexible interface with the ocean.[4] In addition to their high cost, the *Seawolf* class's primary mission, to counter the Soviet submarine threat, has little in common with the increased littoral and strike missions of the post–Cold War period.

The newest class of attack submarine, the *Virginia* (SSN 774) class, was designed as a more affordable platform that retains the acoustic superiority of the *Seawolf* class. The *Virginia* class has improved capability to operate in littoral regions, incorporates a large, integrated nine-man lock-out chamber for special forces insertion missions, and is specifically designed to facilitate future technology insertion. In addition, the *Virginia* class includes non-penetrating photonics masts, eliminating the need for the control room to be located directly below the sail. Eight *Virginia*-class submarines have been procured through fiscal

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[3] Norman Polmar, *Ships and Aircraft of the U.S. Fleet,* Annapolis, Md.: Naval Institute Press, 2005.

[4] RADM J. P. Davis, "USS *Jimmy Carter* (SSN 23) Expanding Future SSN Missions," *Undersea Warfare*, Fall 1999, pp. 16–18.

year (FY) 2006, with the USS *Virginia* (SSN 774) being commissioned in 2004.

The Navy's SSBN fleet is entirely made up of *Ohio*-class (SSBN 726) submarines. The *Ohio*-class boats have 24 missile tubes capable of carrying the Trident C-4 or D-5 missiles and a torpedo capability similar to the *Los Angeles*-class SSNs. The last *Ohio*-class submarine will transition to the D-5 missile by the end of 2007. The first four *Ohio*-class submarines have been or are being refitted as SSGNs. The refit also includes the permanent installation of five-man lock-in/lock-out chambers in two missile tubes. The remaining tubes can be loaded with TLAM launch canisters or with equipment to support up to 66 special-forces troops.[5]

Historically, new classes of submarines have been designed in response to the emergence of a new threat that required a new capability. The most significant requirement of submarine warfare is the ability to maintain an acoustical advantage over an adversary. While the *Sturgeon* class had an acoustic advantage over Soviet submarines, it became obvious in the late 1960s that Soviet submarines had a speed advantage. This drove the U.S. Navy to develop the *Los Angeles* class, which continued to improve the fleet's acoustic performance at higher speeds. The rapid acoustical improvement of the Soviet submarine threat in the late 1970s and early 1980s led the U.S. Navy to develop the *Seawolf* class, which had further speed and acoustic improvements. However, the lack of anything near a peer submarine competitor has changed the driving force behind new submarine designs. The *Virginia* class was initiated primarily as a less costly alternative to the *Seawolf*. The *Virginia* class also incorporates features, such as the large lock-out chamber and a focus on littoral warfare, that are driven not by external threats but by a desire for new or additional capabilities. Finally, the ongoing decommissioning of the first flight of *Los Angeles*–class hulls and the eventual decommissioning of the *Ohio* class require new designs for maintaining the fleet size. It is probable that these last two drivers, desirable new capabilities and fleet-size requirements, will determine the timing of new submarine designs.

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5 Polmar, *Ships and Aircraft of the U.S. Fleet*.

At present, no new submarine class is anticipated until such time as the SSBN fleet may need to be replaced. Allowing sufficient lead time, the design effort for the next SSBN class would have to start sometime around the middle of the next decade (see Figure 2.1).

Submarine Design Phases

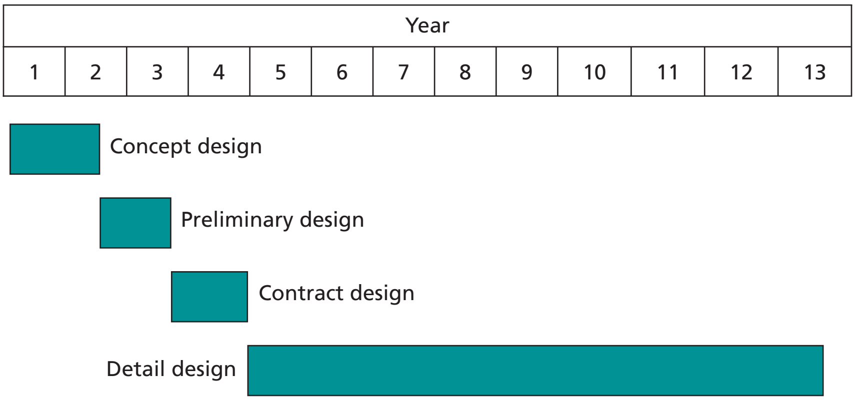
The design of a nuclear submarine, or any naval ship, progresses through four basic phases, with each successive phase adding more detail to the evolving design products (see Figure 2.2).[6] Initial exploratory and point studies result in the start of the *conceptual design phase*. During this phase, future missions and threats are evaluated and weighed against the availability of future technologies suitable to accomplish the required missions. Various concepts are explored and defined, and trade-offs are made among military effectiveness, affordability, and producibility. The conceptual design phase produces a set of "single-sheet" characteristics that define the new submarine's missions, principal operating and performance characteristics, and basic dimensions. Initial estimates are developed of the cost of building the conceptual design.

In the *preliminary design phase*, the preferred concept is matured and top-level requirements are established in greater detail. Subsystems are defined, and alternatives are evaluated for military effectiveness, affordability, and producibility. Detailed analysis of structures, hydrodynamics, acoustics, and combat system performance is also conducted. More detail is added to the "single-sheet" characteristics and performance requirements of the conceptual phase, and budget estimates are refined. The output of this design phase is a set of top-level requirements that feed into the next phase of the design process.

During the *contract design phase*, the top-level requirements are transformed into contract specifications for detailed design and construction of the submarine. Subsystems are defined, initial analyses and testing are completed, projected costs are established, and an initial set

6 When we use the term *design* in this report, we mean all four phases taken together, unless the context clearly indicates otherwise.

Figure 2.2
Traditional Submarine Design Phases



RAND *MG608-2.2*

of ship specifications and contract drawings is prepared. A request for proposal is issued so the shipbuilders can respond and negotiate price.

At the end of the *preliminary design phase*, a contractor is selected to accomplish the detailed design and construction of the new submarine. The contractor initiates the *detailed design phase,* in which the contract drawings and ship specifications of the contract design phase are transformed into the documents and drawings necessary to construct, outfit, and test the submarine. Typically, construction of the submarine starts before all drawings are complete. If this overlap between construction and the development of the drawings needed for construction is too great, problems can occur. Construction is limited by the drawings that are available, and changes to arrangements[7] and specifications can lead to rework during the construction process. One problem faced by the UK's *Astute* program was the start of construction before the detailed design product model was complete enough to provide timely support to certain construction activities. At one point in the program, construction was stopped until the detailed design process could produce the design products needed by the shipbuilders.

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7 *Arrangements* are three-dimensional representations of an object or an area of the submarine.

The traditional design process has changed in several ways from the design of the *Los Angeles* class to the design of the *Virginia* class. These changes include the adoption of a more integrated design/build process known as integrated product and process development (IPPD) and a shift in the roles played by the Navy and the prime contractors in the design process.

The IPPD and Design/Build Process

The four phases of the traditional design process were conducted in a lock-step manner, with a period between each phase where decisions on if, and how, to proceed with the overall design program were made. These intermediate intervals between design phases delayed the process and often resulted in changes to requirements or preferred approaches to a design solution.

The *Virginia*-class submarine used a new seamless design process termed IPPD.[8] In this new process, all of the tasks within the traditional phases of design are still performed, but they are performed in a more parallel manner, with the shipbuilder and the Navy participating in all phases of the design process from the conceptual phase through delivery of the submarine. The IPPD process starts with a systems-definition phase followed by an integrated-design/construction-planning development phase. This change was effected to better integrate design and production planning while ensuring that the life cycle of the platform is considered at every stage of development. IPPD has resulted in designs being completed much more rapidly than under the traditional process.

For the *Virginia*-class design effort, EB also adopted a design/build philosophy that integrated individuals knowledgeable of the construction process into the design teams. Bringing construction expertise to

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[8] Several documents describe the IPPD process, for example Larry Griffin and Robert I. Winner, *Integrated Product/Process Development in Upgrade and Mod Programs*, R. Winner & Associates, April 2003; and Robert I. Winner, *Integrated Product/Process Development in the New Attack Submarine Program: A Case Study*, 2nd ed., R. Winner & Associates, February 2000. EB has also produced various documents describing the design/build process (General Dynamics Electric Boat, *The Virginia Class Submarine Program: A Case Study*, Groton, Conn.: General Dynamics Electric Boat, February 2002).

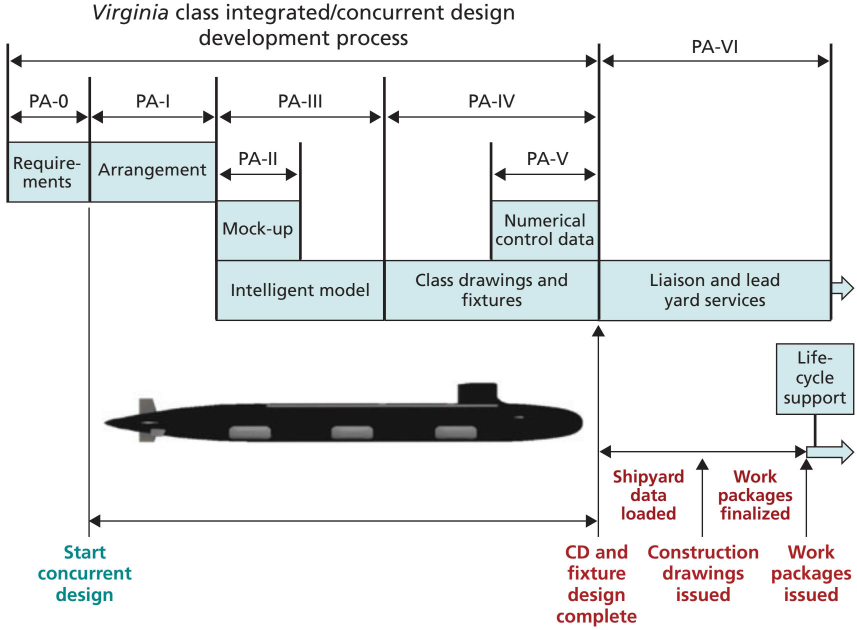
bear early in the design process minimized the type of costly rework during construction that results from a mismatch between what the designers desire and what the builders can efficiently construct. The success of these new processes resulted in the *Virginia* class requiring far fewer design changes during construction than previous classes.

In the new process, design phases are replaced by six "product areas," which correspond to the various design products produced as the design matures (see Figure 2.3). The product areas can be thought of as design phases; however, the sequence of events is more streamlined as there is some overlap between product areas. The first product area is the Requirements Product Area (PA-0), where the specific characteristics of the future platform are established (e.g., shock and survivability requirements). Once the requirements have been established, the specifications are turned into two- and three-dimensional drawings during the arrangement product area (PA-I). Systems and subsystems of the submarine are modeled within the ship structure to evaluate arrangements. Engineering analysis is performed, and multiple design build teams meet to identify possible design conflicts.

Once the arrangements have been established, approval is required from the customer before the design can proceed. Once approval is received, mock-up drawings are created for limited areas of the ship, and design products are further defined. The mock-up drawings are part of Product Area II (PA-II), and the product definition tasks are part of Product Area (PA-III). After the mock-up drawings are approved, system integration reviews, interactive engineering analysis, and approval of the intelligent model are required for final approval of the design configuration. These tasks are performed under the auspices of PA-III, which adds "intelligence" to the model by defining material, parts, etc. Once mock-ups and product definition are approved, class drawings are produced and manufacturing support data are provided to construction activities.

In PA-IV, class drawings are developed, and the development of work package design data is performed as part of Product Area V (PA-V). In the final product area (PA-VI), work packages are finalized and drawings for construction are issued.

Figure 2.3
***Virginia*-Class Design Process**

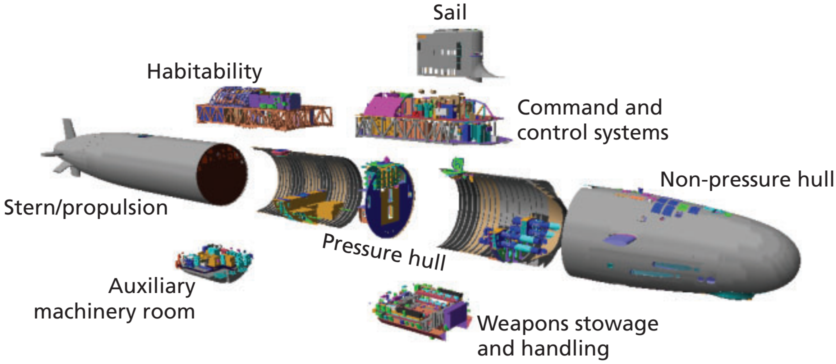


SOURCE: General Dynamics Electric Boat
RAND *MG608-2.3*

This process is carried out for each of eight modules (see Figure 2.4). The modules represent different parts of the submarine and are developed based on how the submarine will be produced. The deliverables associated with each product area are required for each module. However, the sequence in which tasks within each of the product areas are accomplished for each module is different—deliverables are driven by construction activities.

For the *Virginia*-class design program, 15 major area teams (MATs), each covering a contiguous area of the submarine, helped to ensure the design was producible and to facilitate construction planning; they were concerned with their areas and with interfaces to other areas on a cradle-to-grave basis. Each team was co-led by a representative from design and engineering and one from construction. The teams consisted of EB designers and engineers with various skills and from

Figure 2.4
***Virginia*-Class Design Modules**



SOURCE: General Dynamics Electric Boat
RAND *MG608-2.4*

different engineering disciplines and of representatives from construction and planning and from the Navy technical community. Teams numbered from a few people to as many as 50, with certain individuals often serving on more than one team.

In addition to the MATs, 30 *system integration teams* were responsible for the systems distributed throughout the various modules. These teams supplied manpower to the MATs and ensured cross-MAT communication. Providing overall direction and guidance to the various teams were two *major area integration teams*—one for the forward compartment and one for the aft compartment/engine room.

To summarize, the traditional design process that consists of four distinct phases separated by checkpoints that slowed the overall process was replaced in the *Virginia*-class design program by a continuous, integrated process that closely involved not only the designers and engineers from EB but also technical representatives from the Navy and individuals with construction expertise who could provide inputs on the producibility of the design. This process proved successful for the *Virginia* class, was the model for the SSGN-conversion and MMP design programs, and is likely to be the model for the next new submarine design program.

Evolving Role of the Navy in the Design Process[9]

While the overall Navy role—to ensure a submarine design that is safe, effective, and affordable and that meets the nation's national security requirements—has remained constant over time, the method by which the Navy engages in this role has evolved. In the initial classes of nuclear-powered submarines, the Navy was the principal design agent, whereas today, the Navy is but one member of a collaborative design team.[10] This evolution has been driven by internal Navy factors including the desire to reduce the Naval Sea Systems Command's (NAVSEA's) workforce and the need to reduce submarine design and construction costs. These pressures became more pronounced by the simultaneous end of the Cold War and the realization of the high cost of the *Seawolf* class. Ultimately, these pressures have led the Navy to adopt its current actively collaborative approach with industry, illustrated by the IPPD process used to design the *Virginia* class.

This evolution can best be understood by reviewing the Navy's role in the design of several recent submarine classes:

***Los Angeles* Class.** The Navy served as the conceptual and preliminary designer, soliciting independent designs from the two private shipbuilders, Newport News Shipbuilding and General Dynamics Electric Boat.[11] The Navy took the best elements of each design, combining them to create a hybrid preliminary design. Detailed design was accomplished by Newport News Shipbuilding. Both shipbuilders built the finished design product.

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9 Chapter Seven describes in greater detail the Navy's roles and responsibilities in the submarine design process and how their technical resources are currently organized.

10 As used in this report, the term *design agent* refers to the activity that is responsible for conducting the overall design.

11 At the time, Newport News Shipbuilding was a wholly owned subsidiary of Tenneco Corporation. Subsequently, Newport News Shipbuilding was separated from Tenneco and operated independently for some years. In 2001, Northrop Grumman Corporation acquired Newport News Shipbuilding, which today goes by the name Northrop Grumman Newport News.

***Seawolf* Class.** In order to facilitate competition in building the submarines of this class, the Navy instituted a split design strategy.[12] Under this strategy, Newport News Shipbuilding was responsible for the overall design of the ship and the detailed design of the forward end of the submarine. Electric Boat was responsible for detailed design of the submarine's aft end. The Navy served as the facilitator for this design arrangement, which ultimately resulted in increased design and construction costs and delays.[13]

***Virginia* Class.** The *Virginia* class was the first submarine class designed under the IPPD process, as discussed above. EB was awarded the design/build contract; however, the Navy was integrated into the design process through its inclusion in the integrated process teams. The IPPD process was implemented as a means to reduce cost by streamlining the design and construction process.[14]

The synthesis of the design pieces into a total submarine design that is integrated, producible, and timely requires experience and leadership in the broad area of total submarine design synthesis. In addition to these integration and leadership skills, a number of technical skills are required to develop the subcomponents and modules of the design.

Mix of Skills Required to Design a Nuclear Submarine

A wide range of skills and technical competencies are required to successfully complete a submarine design. Recognizing that a gap in design efforts was imminent, EB undertook an effort to categorize the skills required for submarine design. Categorizing skills required that each design task be clearly defined. Then the skills necessary to perform that task are identified. Once all of the skills have been identified, the skills

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[12] U.S. General Accounting Office, *Navy Ships: Lessons of Prior Programs May Reduce New Attack Submarine Cost Increases and Delays*, Washington, D.C.: U.S. General Accounting Office, October 1994, p. 3.

[13] U.S. General Accounting Office, *Navy Ships*, p. 3.

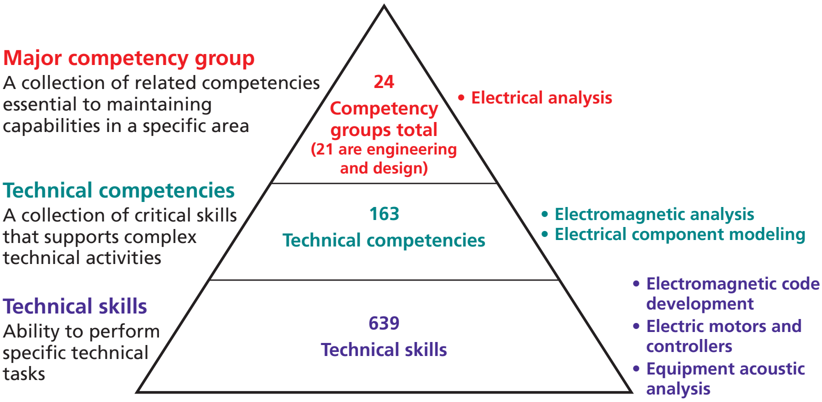
[14] General Dynamics Electric Boat, *The Virginia Class Design Program*, p. 10.

are organized into groups based on similarities. Figure 2.5 shows the results of EB's skill-categorization effort.

Figure 2.5 illustrates how the skills required to perform specific tasks are rolled up into higher-level skill categories. The base of the pyramid represents 639 technical skills identified by EB as required in the nuclear submarine design process. These are technical skills required to perform a specific task associated with the design, such as electromagnetic code development, electric motors and controls development, or equipment acoustic analysis (listed to the right of the pyramid). All of these skills have some electric component, and when grouped together represent an electromagnetic analysis technical competency. In total, EB identified 163 competencies. These competencies make up the middle of the pyramid and are a more aggregated means of categorizing skills. (A single person may possess more than one technical skill or technical competency.)

Similarities between the technical competencies allow further grouping. For example, electromagnetic analysis and electrical component modeling are both forms of electrical analysis, resulting in an electrical analysis competency group. Other technical competency groupings resulted in 24 competency groups at the top of the pyramid. The

Figure 2.5
Categorization of Nuclear Submarine Design Skills



SOURCE: General Dynamics Electric Boat

RAND *MG608-2.5*

competency groupings are further split into designer and engineering groups. There are 19 competency groupings in the engineering group and 5 competencies in the designer group.

To provide a consistent basis of measurement across the two shipyards, we further aggregated EB's competency grouping and a skill classification scheme used by NGNN into 16 skill categories, shown in Table 2.3. For example, we combined EB's mechanical component engineering and mechanical systems engineering competency groups to create a mechanical engineering skill category. In summary, our 16 skill categories are a high-level representation of the 639 technical skills EB identified as required to perform all of the tasks associated with a new submarine design effort. When we refer to these high-level skill categories, it will be important to keep in mind the depth of technical skills that constitute them.

Table 2.3
Aggregated Skill Categories

Group	Skill Category
Designers	Electrical
	Mechanical
	Piping/ventilation
	Structural
	Other
Engineers	Electrical
	Mechanical
	Fluids
	Naval architecture and structural
	Combat System
	Acoustics
	Planning/production
	Testing

Table 2.3—Continued

Group	Skill Category
	Management
	Engineering support
	Other engineering

CHAPTER THREE
Framing the Analysis

Faced with a potentially long gap until the next new submarine class is needed in the fleet, the nuclear submarine design community must understand the implications of different workforce management strategies. As indicated in Chapter Two, the nuclear submarine design process is exceedingly complex and requires a range of designers and engineers that possess not only the requisite technical knowledge but also practical experience in submarine design. In this chapter, we describe how we model the future demand for nuclear submarine design resources and the potential impact of different workforce management strategies that provide the engineering and design resources needed for the next new design effort.[1]

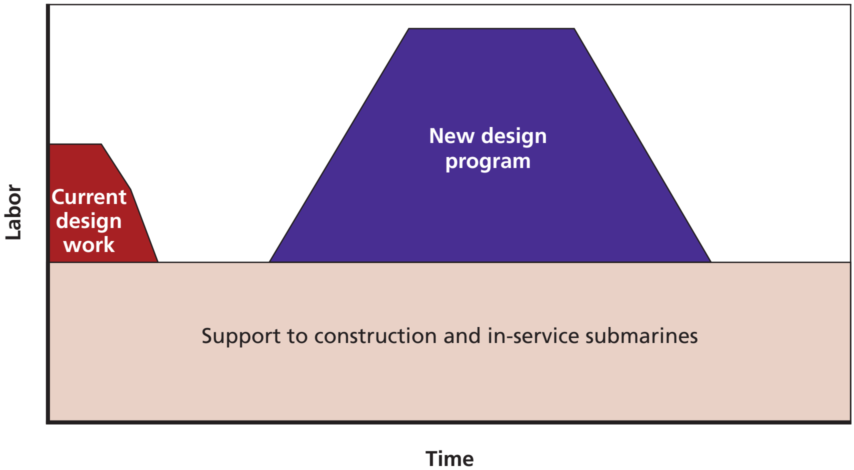
We first describe in general terms how we estimate the costs of various workforce management strategies. We then address the future demand for submarine design resources, including when a new design effort may be required, how long the design effort might take, and the level of effort needed for a new design. We conclude with an overview of the simulation model we developed to estimate the cost and schedule impacts of different workforce management strategies.

1 Here and subsequently, *design* refers to all four phases of the design process taken together, unless specified otherwise.

Methodology for Analyzing Workforce Management Strategies

We begin our analysis by measuring the currently planned future demands for submarine design resources and estimating when the design effort for a new class of submarines might be required. This is shown notionally in Figure 3.1. Both EB and NGNN provided details on the resources required for the design and engineering support to their *Virginia*-class construction programs and for the support of in-service submarines (the bottom area of Figure 3.1). In addition, both prime contractors provided data on the design programs they have under way. For NGNN, this primarily includes the design of the new CVN 78 class of aircraft carriers. That design effort will end when the first of the new class is delivered to the Navy in or around 2015. EB is also participating in the CVN 78–class design effort and has design programs examining cost reduction measures for the *Virginia* class as well as providing support to the DDG 1000 design effort. The demand for designers and engineers at EB will decline as these programs wind down.

Figure 3.1
Notional Demand for Submarine Design Resources



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There are two potential courses of action for the management of the design workforce during the gap before the next new design effort begins. The first option is to let the design workforce go as demand falls and then reconstitute the resources when a new design effort is required. We refer to this as the "do nothing" option. With this option, there is a cost and schedule penalty associated with the time to hire and train a new workforce. The remaining workforce will be less productive due to mentoring requirements, and the new hires will also have lower productivity than more experienced people. Thus, more labor will be required to complete the design than would have been the case without the gap. That is, the demand for labor in terms of man-hours will increase (as indicated by the notional yellow area in Figure 3.2) and so may costs and the time required to complete the effort.

The second option involves maintaining some level of the workforce until the next design effort starts. We refer to this option as the "do something" case, shown in Figure 3.3. In this case, a shipyard would reduce its workforce to match decreasing demands until a predetermined level is reached. The shipyard would maintain this level of designers and engineers as demand drops further, until it rises once

Figure 3.2
"Do Nothing" Option

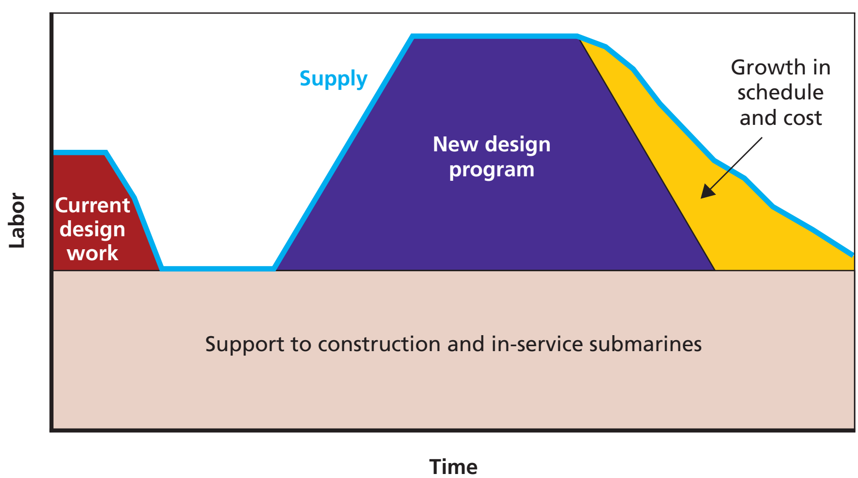

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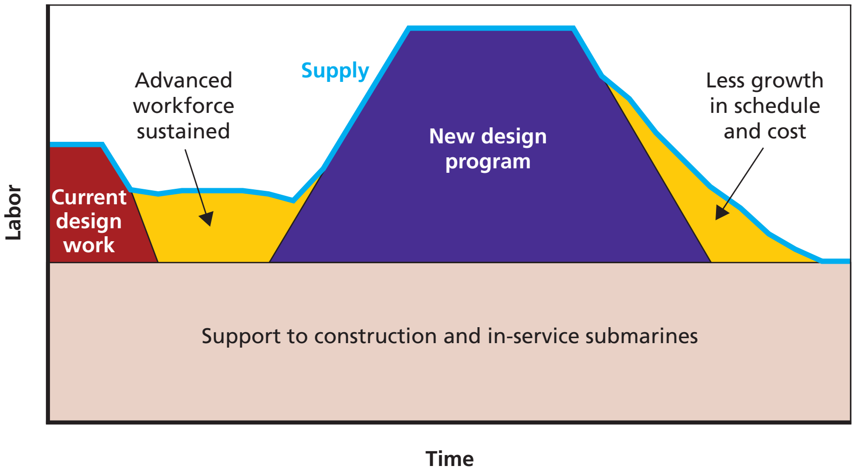
Figure 3.3
"Do Something" Option



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again after the start of the next new design program. Therefore, the "do something" case incurs an additional cost for maintaining a workforce above planned demand. But, starting a new design effort with more people and greater levels of experience can reduce cost and schedule delays of the new design program. There is a trade-off between the cost of maintaining people during a time period where there is no planned work and the cost savings in a new design program associated with maintaining these people (i.e., the difference in the cost and schedule growth areas of Figures 3.2 and 3.3).

To understand the cost and schedule implications of the various options for sustaining submarine design capabilities, we developed a model to simulate the labor response to different workload demands. The approach is akin to an earned value analysis: There is work planned for a given period of time but the actual work accomplished might be greater than or less than the planned level. The amount of work accomplished depends on the size and proficiency of the workforce that is responding to the demand. When the accomplished work is less than the demand, the program falls behind.

Our labor simulation has four main steps:

1. Estimate the demand for design resources from current and potential future design programs. This is the time-phased staffing, based on the assumption that personnel have the proficiency required to complete the planned work on time. We model this demand on a quarterly basis.
2. Determine workforce levels, and their age and experience distributions over time. Based on the demand, workforce demographics, and labor practice constraints, the firms make hiring and termination decisions. This results in staffing that may vary in level and proficiency from that in step 1 and thus may or may not meet the demand.
3. Calculate work accomplished. The model calculates the actual work accomplished based on staffing levels and proficiencies.
4. Determine overall labor costs. Finally, the staffing levels and staffing mix determine the overall cost of labor.

Estimating the Future Demand for Submarine Design Resources

Understanding the future demand for submarine design resources involves answering the following questions:

- When is the next new class of submarines needed in the fleet?
- How long would a new design effort take?
- What is the anticipated demand for designers and engineers during the design program?

When Is a New Submarine Class Needed?

It is difficult to predict when new capabilities will be required to respond to new threats or to undertake new missions. It is possible, however, to predict when existing classes will be decommissioned; therefore, our analysis will focus on fleet replacement as the primary predictor of future design timelines. The submarine portion of the Navy's Long-Range Shipbuilding Plan for the next twenty years is shown in Table

3.1.[2] The plan calls for the authorization in 2022 to build the first of a new SSBN class to replace retiring assets. Therefore, we assume that the SSBN authorization in 2022 will drive the next new submarine design effort.

How Long Would a New Design Effort Take?

We measure the duration of the next new design effort from the start of conceptual design to the delivery of the first of the new class. This duration will depend upon the complexity of the requirement, any schedule and budgetary constraints, and the skill and proficiency of the design workforce. As a benchmark for the design duration, the *Ohio-, Seawolf-,* and *Virginia*-class designs took approximately 15 years. Since we do not have insight into the complexity of the requirements for the next submarine, we use this 15-year duration as a proxy for the duration of the future SSBN design effort.

Design work for the *Virginia* class originated with a series of research and development efforts in the form of point studies in the late 1980s and was completed with the delivery of the first of class in 2004.[3] The timeline in Figure 3.4 shows the sequencing of the important milestones in the *Virginia*-class design program.

Table 3.1
Submarine Portion of Navy Long-Range Shipbuilding Plan (FY 2007 to FY 2026)

Sub Type	Boats per Fiscal Year																			
	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
SSN	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SSGN																				
SSBN																1	1	1	1	1

NOTE: Dates are years of authorization.

2 Office of the Secretary of Defense, "Report to Congress on the Annual Long-Range Plan for the Construction of Naval Vessels for FY 2007," March 23, 2006.

3 Point studies are conceptual designs with payload, arrangements, speed, depth, weight, and stability calculated for study purposes.

Assuming a seven-year build period for a submarine, authorization of the new SSBN class in 2022, and a 15-year period from conceptual designs to the delivery of the first of class, the new SSBN design effort would begin in 2014 (see Figure 3.5, first bar).

Figure 3.4
***Virginia*-Class Design Timeline**

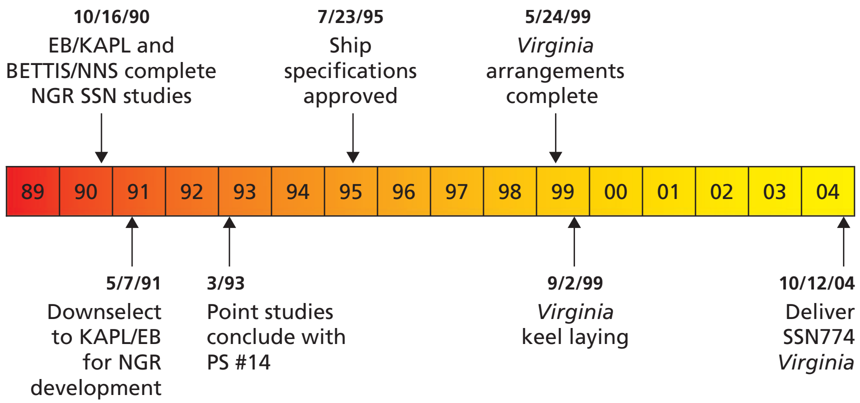

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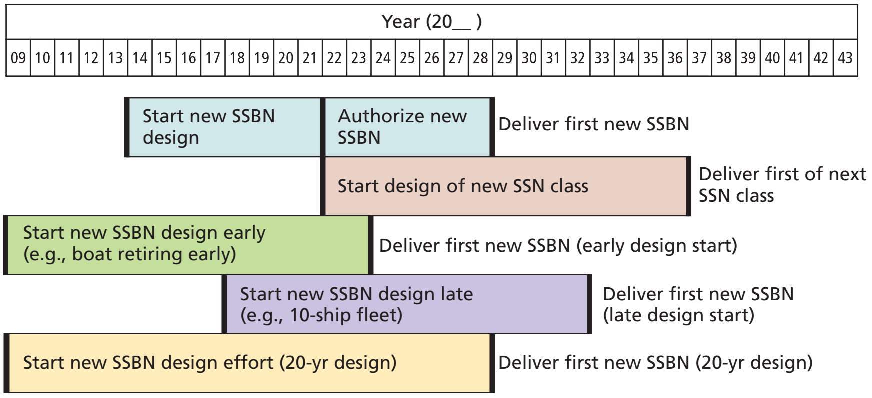
Figure 3.5
Relationship Between Start Dates and Design Durations



NOTES: Heavy vertical lines indicate dates. Colored bars indicate design durations.
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What Will Be the Level of Effort for the Next New Submarine Design?

As with the duration of the design effort, the magnitude of the demand for submarine designers and engineers depends on the complexity of the design, on schedule and budgetary constraints, and on the contribution of computer design software tools. As a starting point for estimating the level of effort required for the next new submarine design, we use the effort required for the *Virginia* class.

The *Virginia*-class design effort took an estimated 35 million man-hours over the approximately 15-year design period.[4] This estimate includes all work that was subcontracted to EB from the nuclear laboratories. The demand profile for the *Virginia* class, including key milestones, is shown in Figure 3.6. Note that the design is considered complete when the drawings are finished, approximately two years prior to delivery of the lead ship.

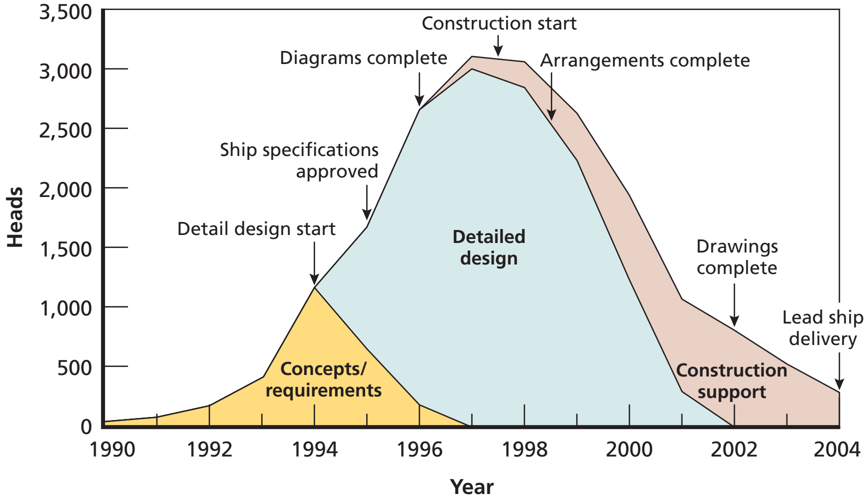
To summarize our assumptions about the timing and magnitude of the next new submarine design effort, our base case assumes the start of a new SSBN design in 2014 that will last 15 years and require approximately 35 million man-hours of design and engineering effort.

Alternative Demand Assumptions

Because of the uncertainty surrounding the start of the new design, its duration, and the level of effort required, we examine various ranges around our base-case assumptions.

4 Early in the *Virginia*-class design effort, EB recommended that the Navy add 3.2 million hours to the design contract to perform functions that had previously been accomplished under the separate lead submarine construction contract. These "delivery" functions included purchase order procurement specification drafting, work package preparation, production planning, and computer-aided design/computer-aided manufacturing (CAD/CAM) numeric control data file preparation. EB believed performing this effort simultaneously with the design would improve both design and production efforts to the benefit of the entire program. The Navy approved the recommendation and funded this effort in the design line item of the design/build contract. EB ultimately spent about 3.6 million hours on this effort. We do not include these hours in our estimate of the design workload for the next new submarine design program.

Figure 3.6
Profile of the *Virginia*-Class Design Effort



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Range of Potential Design Start Dates

The current planning documents call for authorization of a new SSBN class in 2022 to replace the *Ohio*-class submarines, which begin retiring in 2029. This authorization is based on a planned future SSBN force structure of 14 submarines and a 45-year operational life for the *Ohio* class. The operational life and force structure requirements could change, thereby altering the planned replacement date. Future operational requirements could result in a reduced SSBN force if threats change or if ballistic missiles could be deployed in another manner such as with an SSGN. Also, the *Ohio*-class service life of 45 years is a fleet goal based partly on engineering estimates made when the class was designed. Those estimates could prove optimistic (e.g., because of increased utilization), resulting in the need to retire the boats before the 45-year service life is achieved. Table 3.2 shows alternative new SSBN design start dates for different SSBN force structures and *Ohio*-class operational lives. Although our base case analysis centers on a design start of 2014, we examine the impact of start dates ranging from 2009 to 2018.

Table 3.2
Possible Start Dates for New SSBN Design

	Start Date		
Fleet Size	40-Year Service Life	42-Year Service Life	45-Year Service Life
10	2013	2015	2018
12	2011	2013	2016
14	2009	2011	2014

Range of Design Workload Estimates

Though the *Virginia*-class design effort is the base case for our analyses, the workload for a future SSBN design effort may differ from that level. Improvements in the capabilities of computer design tools, the reuse of existing technologies and designs, and greater efficiencies in the performance of designers and engineers may lead to a reduction in the number of man-hours required for the next new design. On the other hand, the ballistic-missile-related design requirements for a new SSBN class, the inefficiencies associated with a potential change in design tools, or the loss of learning by the design and engineering workforce during a design gap may lead to design efforts greater than what was required for the *Virginia* class. Because of the uncertainties surrounding the magnitude of the next new design effort, we evaluate cases where the design effort requires 30 percent fewer man-hours and 30 percent more man-hours than our base-case assumption of a 35 million man-hour design program.

Alternative Design Duration

Drawing on the experience of the *Ohio*- and *Virginia*-class designs, our base case assumes a 15-year design effort. However, the fact that those design efforts took approximately 15 years may have resulted from past budgeting and scheduling processes. Typically, the in-service date of a new class of submarines is determined and then the efforts to design and produce the new class are funded through the budgeting process. Because budgets are typically constrained and there are numerous

demands for scarce funding resources, budget decisions are pushed to the future as much as possible. Also, as shown in Chapter Two, previous new submarine design efforts often overlapped with prior new design efforts, resulting in the Navy and the prime contractors scheduling design activities to make efficient use of design and engineering resources across programs. Therefore, our base-case assumption of a 15-year design effort may not accurately represent the duration of the next SSBN class, especially when there is a gap of several years between the end of the *Virginia*-class design effort and the start of the next new design.

Because of the uncertainty surrounding the duration for a new design effort and the expected gap in workload, we consulted with the prime contractors to understand the feasibility and implications of starting a new design effort earlier but fixing the delivery date of the first submarine of the new class. The objective was to stretch and "level-load" the design work so that there is no steep ramp-up to a peak level of manning, which is sustained only briefly and followed by an equal ramp-down in the demand for design and engineering resources (as shown in Figure 3.6). A resulting 20-year design profile assumes the desired delivery date for the first of class and the total design workload are fixed. Thus, the design effort is stretched and the peak demand for designers and engineers is reduced, with the peak held constant for several years. A notional 20-year design effort with key milestones is shown in Figure 3.7 (see also the bottom-most horizontal bar in Figure 3.5).

This type of stretched design effort has not been done in the past and there are risks associated with such an effort, including

- an additional five years of overhead-related costs such as for design program management
- additional iterations of technology refresh cycles
- the increased opportunity to change requirements or perform additional reengineering.

There are also many potential benefits of moving to a stretched design profile. It allows for workforce stability, which can lead to

improvements in productivity. In addition, because fewer people are needed, there may be cost savings associated with fewer fixed costs (i.e., less management and oversight).

Summary of the Analysis Options for the Next New Submarine Demand

Table 3.3 shows the range of demand-related values used in the analysis of different options for sustaining the submarine design workforce.

Figure 3.7
20-Year Design Effort

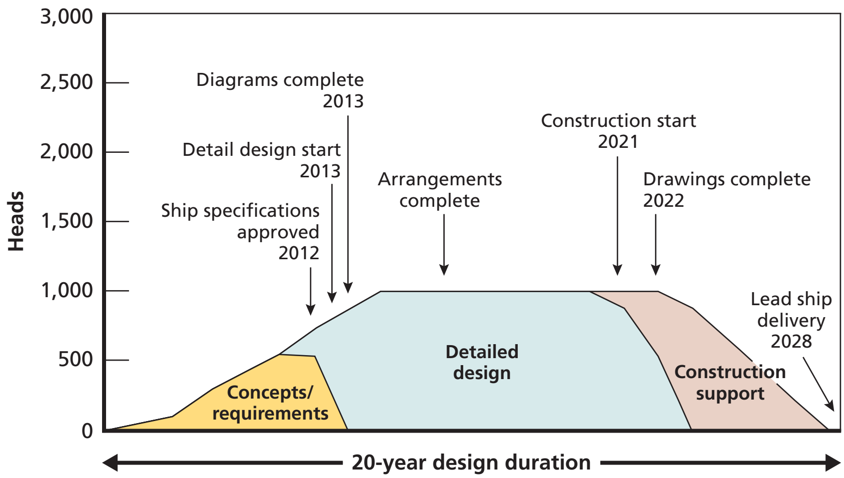

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Table 3.3
Range of Cases for Evaluation

Variable	Base Case	Range of Alternatives
Design start	2014	2009 to 2018
Workload	*Virginia* class (~35 million man-hours)	*Virginia* class ±30%
Duration	15 years	20 years

In addition to the range of cases shown in Table 3.3, we consider options where the total design effort is performed by EB or by NGNN and options where the two prime contractors share the design effort. Since sharing the design effort may result in inefficiencies or extra workload for management functions, we consider cases where the total workload increases due to the design effort being shared.

Managing the Submarine Design Workforce Requires a Long-Range View

The various cases we have developed for analysis address the next new design effort. However, effectively managing design resources to ensure they are available when needed requires a long-range view of the industrial base. Without this long-range view, near-term decisions may create future gaps in design programs or may result in an overlap in design programs that strains the ability to meet the combined demands.

If the next new design program is for an SSBN class, it is reasonable to assume that the new design program following that would be for a new SSN class. Planning documents do not indicate when a new attack submarine will be required. In addition, there is currently no public record of the total number of *Virginia*-class submarines that will ultimately be procured, and therefore, no definite indication of when the *Virginia* class will need to be replaced. However, we can postulate that when the first of the *Virginia* class retires, it will likely need to be replaced with a new design or upgrade.[5] If the operational life of the *Virginia* class is 33 years and the first of the *Virginia*-class submarines will be replaced by a new SSN design, then the first of the new SSN class is required in the fleet by 2037. Assuming a 15-year duration from the beginning of conceptual designs until the delivery of the first of class, the new SSN design would start in approximately 2022 (see Figure 3.5, second horizontal bar from the top).

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[5] It is reasonable to assume that the planned long production span for *Virginia*-class submarines will result in different flights incorporating spiral development efforts. For example, the 62 boats of the *Los Angeles* class encompassed three separate flights, with flights 2 and 3 requiring substantial design efforts.

Using notional workload demand profiles, Figure 3.8 illustrates how the design workforce demand of the base-case SSBN start in 2014 integrates with the demands for the follow-on SSN design program (assuming both programs have a 15-year duration). The decline in workforce demands from the SSBN program overlaps with the increasing demands of the follow-on SSN program. This creates a small "valley" in demand, but sustains a demand for a large number of designers and engineers. If both design programs were stretched to 20 years, the valley would be greatly reduced and the demand for designers and engineers would be fairly constant over the two programs.

Figure 3.9 shows the impact on workforce demand if a new SSBN design program taking 15 years must start in 2009 because a replacement submarine is required sooner than expected (see Figure 3.5, third horizontal bar from the top). An early start of the new SSBN design program causes a significant gap in demand for design resources before the follow-on SSN program commences. This results in the same problem faced today by the design industrial base.

Finally, Figure 3.10 shows the impact of starting the new SSBN design later than currently expected. If future SSBN fleet requirements drop from 14 to 10, the next new SSBN design may not start until 2018 (see Figure 3.5, fourth horizontal bar from the top). When coupled with a follow-on SSN start in 2022, the demand for design resources grows substantially as both programs' design efforts are ongoing at the same time. It would be difficult to meet these high levels of design resource demand, especially after experiencing a design gap of over a decade.

Although the future always holds a good deal of uncertainty, the Navy should consider both the near-term and long-term implications of decisions intended to sustain submarine design resources.

Modeling Workforce Management Strategies

Now that we have addressed the issues and assumptions about the future demands for submarine design resources, we describe how we modeled the costs of different workforce management strategies to meet those demands.

Figure 3.8
Future Impact of Expected SSBN Design Effort

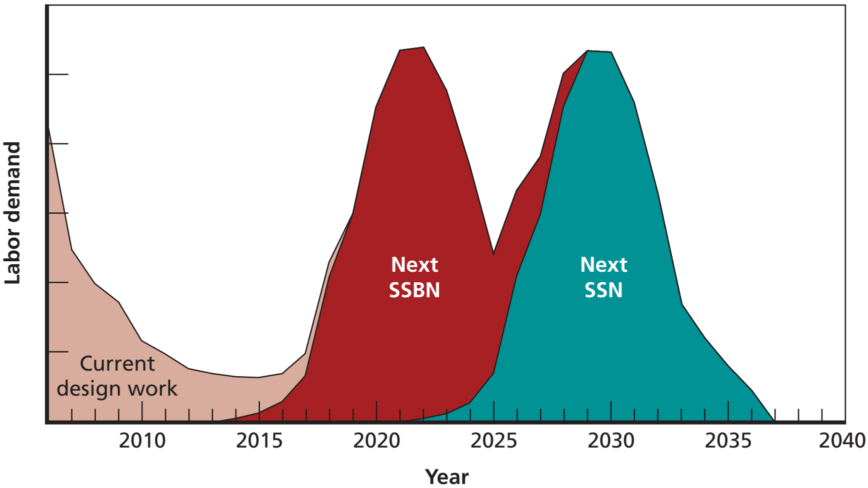

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Figure 3.9
Future Impact of an Early SSBN Design Start

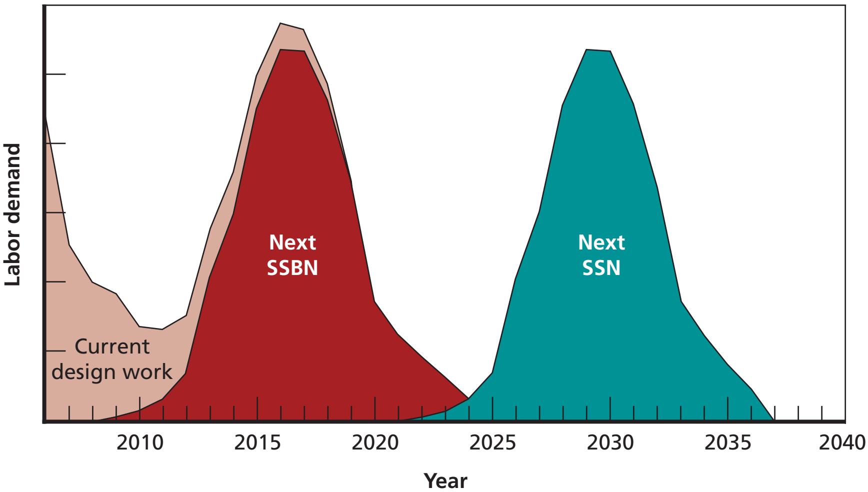

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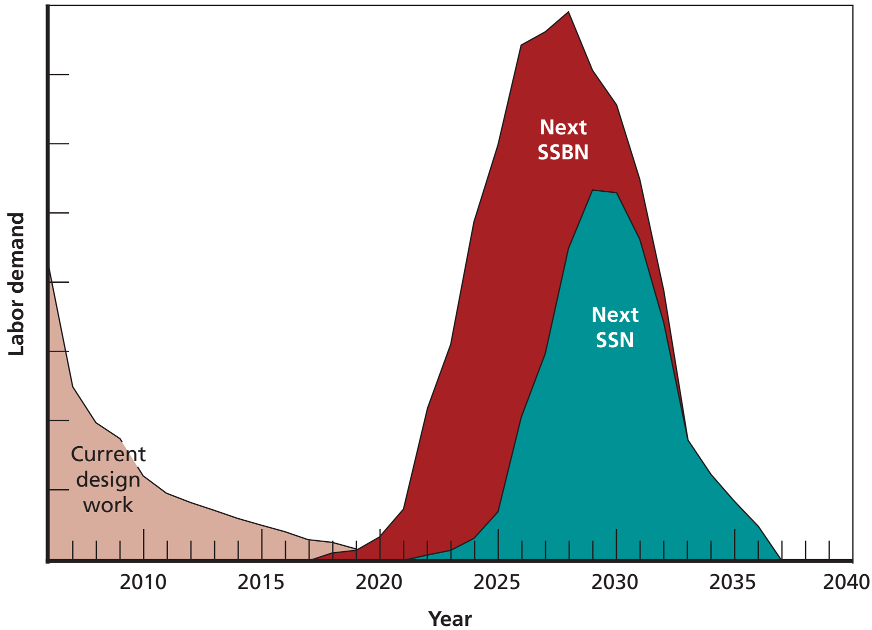
Figure 3.10
Future Impact of a Delayed SSBN Design Start



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A gap in workload can have a significant effect on a workforce's ability to efficiently and effectively execute programs. Such gaps typically lead to initial reductions in staff (i.e., layoffs), which means that knowledgeable and skilled workers are lost to a firm and, perhaps, to an industry. The gap is then followed by a buildup, as a firm tries to reconstitute its workforce. The longer the gap, the more severe the loss of workers and the greater the likelihood that these lost workers will not return once work restarts. The consequence of such a loss of skills and knowledge is that future work, when it does restart, is done less productively (e.g., more hours and mistakes) and may not finish at the required time (as new workers are assimilated into an organization slowly). Furthermore, as employment levels change, there are additional labor costs, such as training costs, hiring and recruiting expenses, or termination payments. Therefore, gaps in workload can be quite expensive and can significantly disrupt schedules.

RAND has examined the implications of work gaps in defense weapons system production. *Reconstituting a Production Capability* summarizes the restart experience for 11 aircraft programs.[6] The authors found that the time from restart to first delivery (while shorter than that for a new program) ranged from approximately 10 to 40 months. Furthermore, the first-unit-hours after restart were less than the first-unit-hours for the initial production run but higher than the hours for the last unit before production stopped (so-called loss-of-learning). *The U.S. Submarine Production Base*: *An Analysis of Cost, Schedule, and Risk for Selected Force Structures* examines the cost, schedule, and force structure implications of gapping production of nuclear submarines for several years, concluding that a gap of a few years would increase production costs by billions of dollars.[7] Similarly, *The U.S. Aircraft Carrier Industrial Base: Force Structure, Cost, Schedule, and Technology Issues for CVN 77* examines the timing of the start of production for CVN 77.[8] The authors found that an earlier than planned start of CVN 77 would be less costly as it would minimize a significant workload drop at Newport News Shipbuilding. All of these studies found that a gap in production and a subsequent restart had significant financial consequences.

The present study is concerned with a gap in design and engineering work. While there are some similarities to the issues that arise from a production gap, there are also important differences. For example, one typically would not expect as much cost improvement or "learning" to occur between new design and engineering efforts as between new production efforts, because each new design effort is distinctive in terms of its requirements and capabilities. Thus, one would expect smaller restart inefficiencies for design and engineering than one would

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6 John Birkler, Joseph Large, Giles Smith, and Fred Timson, *Reconstituting a Production Capability*, Santa Monica, Calif.: RAND Corporation, MR-273-ACQ, 1993.

7 Birkler et al., 1994.

8 John Birkler, Michael Mattock, John Schank, Giles Smith, Fred Timson, James Chiesa, Bruce Woodyard, Malcolm MacKinnon, and Denis Rushworth, *The U.S. Aircraft Carrier Industrial Base: Force Structure, Cost, Schedule, and Technology Issues for CVN 77*, Santa Monica, Calif.: RAND Corporation, MR-948-NAVY/OSD, 1998.

for production. However, this smaller restart penalty might be offset by a larger one from another source. Whereas production skills might take on the order of three to four years to mature, design and engineering skills take many years. Some technical specialties might even take decades to develop. On this account, then, the loss of a skilled design and engineering workforce resulting from a gap (and its reconstitution with inexperienced workers) might have a greater effect on cost and schedule than a gap in production. Also, the resource pool of workers—particularly in the high-end technical specialties—is more limited in the design and engineering fields. For example, there are few domestic sources of skilled naval architects in the United States.[9]

The facilities implications of a gap in design and engineering are less dramatic compared with production. There is not the same level of facilitation (e.g., equipment and tooling) that must be maintained during a work gap. The primary facility for design and engineering is office space, which can be mothballed quite readily. The only major "tool" associated with design and engineering is the computer-aided design/computeraided manufacturing (CAD/CAM) system. These systems change and are updated frequently enough that maintaining a legacy version is both impractical and undesirable during a gap. Thus, any refresh costs of the design tool would likely be incurred with or without a gap.

Therefore, in quantifying the effects of a design and engineering gap we focus primarily on understanding how changing employment levels influence efficiency. We consider the following issues:

- How long does it take to reconstitute a workforce and what limits the rate at which it can be done?
- How does worker productivity change with work experience?
- How do workforce age demographics mitigate or exacerbate the impact of a gap?
- What are the costs to recruit and train new workers?
- How does the length and depth of a gap influence performance?

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9 See Chapter Five for further discussion on the availability of designers and engineers.

We developed a workforce simulation model to quantify the effect of these issues. The model helps us to better understand how a gap (low demand followed by an increased demand) alters the labor workforce and consequently affects cost and schedule. The simulation is a time-step model that changes the workforce (employment) levels in response to demand and other inputs. The simulation processes the flows of workers (both gains and losses) with each time step. Workers can be gained through only one way—new hires. However, workers can be lost through a variety of mechanisms: retirement, attrition (not related to retirement), or layoffs. Furthermore, workers progress upward through the experience levels the longer they are employed.[10] The model tracks the number of workers over time by skill category,[11] age bracket, and experience level.

The model requires a set of input data that includes normal attrition and hiring rates; age demographics; the costs of hiring, terminating, and training designers and engineers; and how proficiency is gained over time. Survey instruments were sent to both EB and NGNN to assemble these input data.[12] Because of their unique methods for developing and using designers and engineers on new design programs, EB and NGNN provided slightly different values for the various rates, factors, and costs. When modeling the cost and schedule impacts at EB and NGNN, we use consistent assumptions for the future SSBN demands but use the workforce-related factors unique to each organization.

Impact of Schedule Growth on Workload

If sufficient numbers of properly trained and experienced resources are not available when a new design effort starts, a backlog of design work will grow because of the inexperience of the workforce and the completion of the design effort will be delayed. This results in the cost

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[10] The technical details of the model and the sensitivity of model outputs to various input variables are provided in Appendix A.

[11] The analysis results shown in Chapter Four are based on grouping our 16 skill categories into two—designers and engineers. Chapter Five reverts to the 16 skill categories.

[12] The survey instrument is reproduced in Appendix B.

and schedule growth previously indicated in Figure 3.2. In matching the ability of the workforce to accomplish productive work to the time required to perform that work, the model calculates how long the desired design effort will take and how many designers and engineers must be hired to accomplish the work. It then computes an additional work penalty resulting from the growth in the design schedule. Table 3.4 shows the relationship between cost and schedule growth for a number of previous submarine design programs. Based on these data, we assume that a one percent growth in schedule results in a one percent growth in design costs.

Longer design durations may result in other cost effects. Because the desired delivery date for the first of a new class is often fixed, construction may start before sufficient design details are complete. This could lead to an increase in construction costs from rip-outs or reworks caused by the incomplete designs. Such an increase in construction costs was experienced by the United Kingdom's *Astute* program when the output of the design process was insufficient to support construction efforts. We note that other costs associated with a longer-than-planned design effort may exist, but our model focuses solely on the cost impacts to the workforce involved in the various design efforts.

Our modeling methodology also makes no adjustments for risks associated with allowing the workforce to fall to a particular level. This would include behavioral effects caused by a shrinking industrial base such as higher attrition rates from the industry, reluctance of potential new employees to join an industry that is viewed as being volatile

Table 3.4
Man-Hour and Schedule Growth Percentages for Submarine Design Programs

Design Program	Growth in Design Cost (%)	Growth in Design Schedule (%)
Ohio	42	45
Seawolf	212	107
Virginia	12	12
Astute	112	84

and uncertain, or an executive decision by one or both firms to leave the submarine design business. We assume that the required skills are available and that the firms can reconstitute the workforce regardless of how low their design and engineering resources fall.

Total Cost of Labor

It is important to understand the cost trade-offs between various components of the workforce, such as the cost of sustaining resources above demand during the gap and the cost of a new design program when starting with different levels of resources. To understand these trade-offs, we calculate labor costs for each of four types of workload. The four categories are in-service support and logistics work, new design work, other fixed work, and gap work. The support and logistics workload includes support to construction and to in-service submarines. New design work is the model input estimate of the workload required for the next new design effort. Other fixed work, as provided by the shipyards, consists of current and planned design work. Gap work is the amount of work required above current planned work that is needed in order to maintain a specified number of employees at the shipyard.

The workforce required to meet demand is divided into two categories, designers and engineers, since the direct and indirect labor and overhead costs differ for these two general skill groupings. EB and NGNN provided the various direct and indirect labor costs for designers and engineers. The following costs are then calculated:

- ***Direct Labor Costs.*** Direct labor costs here refer to the hourly wage rates.
- ***Indirect Labor Costs.*** Indirect labor costs include employee fringe benefits; overhead costs; costs associated with training, hiring, and firing; general and administrative costs; and fee/profit. Employee fringe benefits include vacation, sick days, holidays, and benefits such as medical insurance and retirement payments. Overhead costs include fixed costs such as facilities and utilities. General and administrative costs include items such as management salaries and accounting expenses. Hiring costs include recruiting and interview costs, relocation expenses, and new hire orienta-

tions. Firing costs include severance processing and any severance that is due. Training costs include new-hire and experienced-staff training costs.

- ***Schedule Penalty.*** As discussed, we assume a one percent growth in cost for each one percent growth in schedule. After the schedule increase is calculated, a cost penalty is developed based on the magnitude of the increase. The penalty is then applied to the cost of labor.

In order to allocate indirect labor costs to labor hours, we use a fully burdened labor rate. The rate includes the direct and indirect labor costs. The fully burdened labor rate is a function of the total hours of direct work in the shipyard. As the total hours of work increase, the fixed costs are spread over more hours. Estimating the change in the rate as compared with the change in work hours is critical for determining how increasing or decreasing total hours in the shipyard affects program costs. The function used for calculating the new rate is Fully Burdened Labor Rate = (burden slope)/(total direct work at site in FTEs) + burden base.

The burden slope and base are estimated by regressing the burdened rate on the reciprocal of the total direct work. The slope from the regression is the burden slope and is represented by a percentage. The burden base is the constant estimated by the regression. EB and NGNN provided the data required for the regression.

In summary, the total cost of the labor is equal to the sum of the costs over all time steps plus the cost growth associated with the schedule penalty. In order to estimate the total cost of labor, the direct and indirect costs for designers and engineers are summed at each time-step, starting in 2006 up through the completion of the last expected design effort. The sum of the costs over all of the time-steps is the total cost of labor for completing all of the work in the shipyard. The total cost of labor is equal to this cost plus the cost penalty of being late.

Treating Design Resources Devoted to Support Functions

As mentioned, we calculate the costs associated with the design resources devoted to the support of construction efforts and the sup-

port of in-service submarines. We use the projected workloads and direct labor rates provided by the prime contractors to estimate the direct costs of the support workforce. The overhead rate applied to the direct costs varies as a function of the work in the other three cost categories. Although we include the cost of designers and engineers serving in the support functions, we do not consider these resources when rebuilding the workforce to meet a new design effort. That is, we do not assume that the support resource base will act as mentors for new hires and we do not count their proficiency levels when calculating the proficiency of the workforce devoted to a new design.

We make this assumption because, although the designers and engineers in support functions and those resources working on new designs have similar skills, they apply and use those skills in different ways. Designers and engineers in the support functions deal with emerging issues with existing designs and are typically more system and subsystem focused than designers and engineers working on the design of a new submarine class. They also use computerized design tools in different ways; the designers and engineers in support functions examine and modify existing three-dimensional computer drawings whereas those resources in the new design effort use the computerized tools to develop a new total, integrated, and producible set of drawings for a new submarine class. In fact, both prime contractors believe that designers and engineers who work in the support area for more than a year begin to lose their proficiency for new design efforts.

Our assumption that the resources devoted to support efforts should not be counted when rebuilding the design workforce could be viewed as conservative. Designers and engineers could be rotated between support functions and new design efforts, providing a broader base of experience when rebuilding the design workforce. Or, experienced designers and engineers working in the support area could act as mentors for new hires in the new design area. However, such management actions might negatively impact the efficiency of the design resources supporting construction or in-service submarines, leading to increased costs for that function.

Interpreting Results of the Analysis

The following caveats apply to the results of our analysis:

- Our model does not produce budget-quality cost estimates. The results are best viewed as relative differences in the costs of alternative workforce management strategies rather than the absolute cost of any one strategy.
- All costs are estimates subject to estimating errors associated with future uncertainties. We do perform some sensitivity analysis on various workforce-related variables. Nonetheless, we cannot test for uncertainties for all conceivable parameters, so care should be taken in interpreting small differences in cost and other outcomes.
- Workforce-related model inputs are based on data received from EB and NGNN. We compare these data to similar values from other shipyards to ensure their reasonableness.
- We assume that both shipyards currently have the critical skills and proficiency necessary for submarine design. We do not test this assumption, which has implications for our results.

Summary

To summarize our analysis methodology, we consider two options for managing the future design workforce. Under the "do nothing" option, the prime contractors would adjust their workforce to meet known demands. In the "do something" option, the prime contractors would employ a number of designers and engineers above known demands to serve as a foundation to rebuild the workforce for a new design effort.

For each option, we start with the known demands—the design work "on the books" that involves support to construction efforts or in-service submarines, as well as any new design efforts for surface ships, such as the CVN 78 class, or for major modifications to the *Virginia* class. We then estimate when a new design effort might begin, how long it would take, and the magnitude of the workload demand. Using the current 30-year shipbuilding plan as a guide and assuming that

the next design effort would be similar to that of the *Virginia* class, our base-case estimates for the future demand assume the start of a new SSBN class design in 2014 that would last 15 years and require approximately 35 million man-hours of labor. Because of future uncertainties, we also examine the sensitivity of the results to different start dates, durations, and workloads.

The simulation model then steps through time adjusting the workforce according to the management option ("do nothing" or "do something") and, based on the workforce's composition when the new design effort starts, calculates the management option's impact on the schedule and workload of the new effort. Direct and indirect costs are calculated to compare the total costs of sustaining various numbers of designers and engineers during the design gap.

CHAPTER FOUR

Effect of Different Options for Managing Design Resources

This chapter presents the results of analyzing different policies for sustaining submarine design resources using the model described in the previous chapter. We begin with our base-case assumptions and estimate the cost and schedule impacts of sustaining different levels of design resources at EB and at NGNN, assuming the total effort is performed by one of the two organizations.

Because of the uncertainty surrounding our various assumptions, we examine the sensitivity of the cost and schedule impacts for different

- design start dates
- design workload requirements
- design durations
- distributions of the design work between EB and NGNN
- workforce hiring, training, and proficiency factors.

In the presentation of the cost results that follow, we describe the cost implication of the gap minimization strategies in terms of fixed dollar costs.[1] We choose this metric for ease in presentation and so that readers can easily identify potential budgetary implications, such as how much money needs to be programmed earlier versus how much will be saved later. In a formal cost-benefit analysis, the cost results

1 The cost estimates in this chapter are in constant FY 2006 dollars but are nondiscounted.

are generally given in terms of net present value (NPV). NPV allows one to balance the different timings of cash flow by accounting for the cost of money. NPV is a useful metric in deciding whether or not to proceed with a course of action, but relating the NPV results to actual cost implications is difficult. NPV dollars do not relate to any cost that most readers would readily recognize. We do present the formal NPV analysis in Appendix E. The results from the fixed dollar and NPV perspectives are similar because the differences in cash flow are across only a few years and the cost of money is small.

Analyzing the Base Case

To reiterate, our base-case assumptions include a start of a new SSBN design effort in 2014 that lasts 15 years from the start of conceptual design to the delivery of the first submarine in the class. The total design workload is similar to that required for the *Virginia* class (approximately 35 million man-hours). The impact on schedule of sustaining different numbers of designers and engineers if EB performs the design effort is shown in Figure 4.1. If no additional design resources are sustained (i.e., the "do nothing" option), it will take approximately three years longer to design the ship than the 15 years we assume (note that the future demand for EB design resources does not drop below approximately 400 for the time period examined). The schedule delay is reduced as additional resources are sustained. If EB maintains approximately 800 designers and engineers, the first of the new submarine class will deliver on time.

The cost impact of sustaining different levels of design resources at EB is shown in Figure 4.2. The x-axis represents the different levels of the workforce sustained. The y-axis shows the cost difference between sustaining the additional workforce and the "do nothing" option. The negative cost differences (labeled as "Cost Avoidance") suggest the cost of sustaining additional design resources is less than the costs associated with rebuilding the workforce in the "do nothing" case. As more designers and engineers are sustained, the cost avoidance grows, until sustaining approximately 800 designers and engineers results in a cost

Figure 4.1
Base Case: Schedule Impact of Sustaining Various Levels of Design Resources at EB

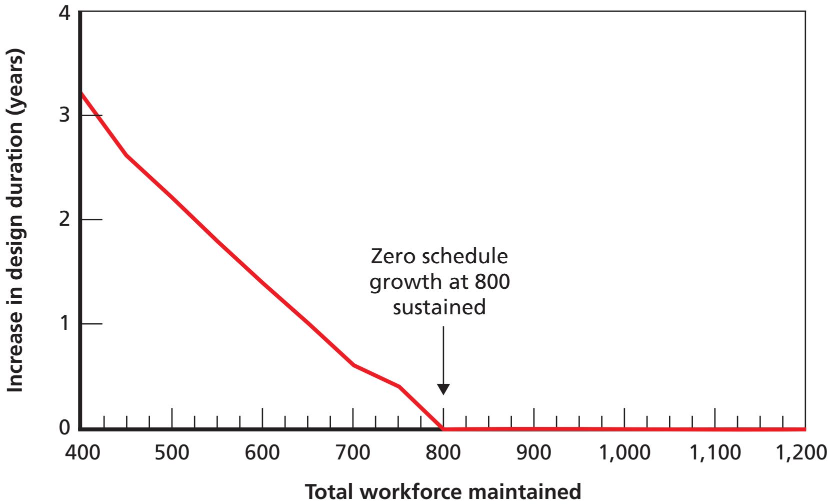

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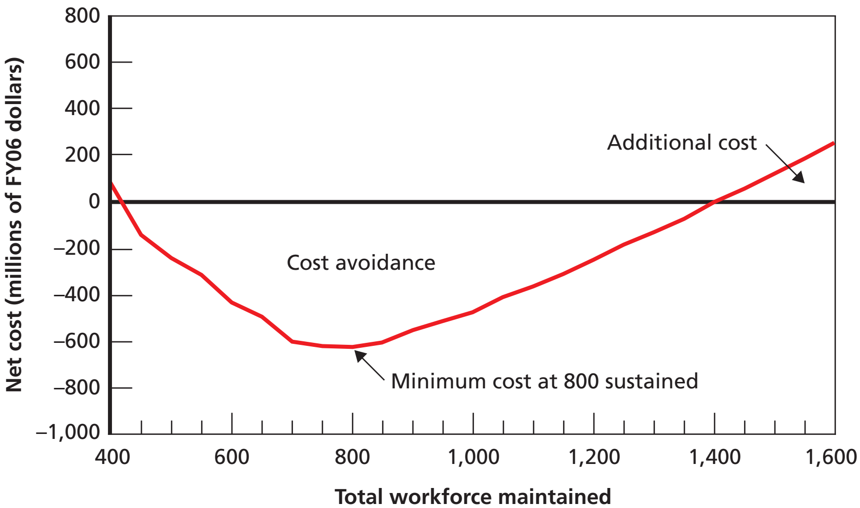
Figure 4.2
Base Case: Cost Impact of Sustaining Various Levels of Design Resources at EB



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avoidance of approximately $600 million. This cost avoidance is for the four categories of design work mentioned previously: support to construction and in-service submarines during the period of analysis, work currently on the books, sustaining additional resources during the gap, and the cost of the new design effort. We refer to this workforce level as the *least-cost workforce to sustain*. Sustaining resources beyond 800 results in greater costs during the design gap compared to the reduction in cost increases in the "do nothing" option. However, it is still less costly to maintain people than to do nothing up until approximately 1,400 people. Maintaining more than 1,400 people becomes more costly than the "do nothing" option.

Figure 4.3 shows the schedule impact of sustaining different numbers of designers and engineers at NGNN. If a new design program is started at NGNN and no workforce is sustained above currently planned work, the delivery of the first of class will be delayed by approximately seven years. This delay is reduced as additional resources are sustained until NGNN reaches a level of approximately 1,000 designers and engineers. Sustaining more than this number has no further impact on the schedule of the program.

The consequence of "doing nothing" at NGNN is different from the consequence of "doing nothing" at EB because the known design work (i.e., the work on the books) and the workforce parameters between the two companies differ. The end of the CVN 78 design work in approximately 2015 will result in a lower known demand at NGNN compared to the known demand for EB, so the starting position when rebuilding the workforce is different and the cost and schedule impacts will be greater. Also, the growth rates, productivity, attrition, and skill mix requirements differ between the two yards. These factors are critical components of the equations for determining the time and cost to reconstitute a design workforce.

The cost impact of sustaining various numbers of designers and engineers at NGNN is shown in Figure 4.4. Compared to the "do nothing" case, the total cost of completing all design-related work at the shipyard decreases as more and more people are maintained above currently planned design work. If approximately 1,050 people are maintained, the total cost to accomplish scheduled work is approximately

Figure 4.3
Base Case: Schedule Impact of Sustaining Various Levels of Design Resources at NGNN

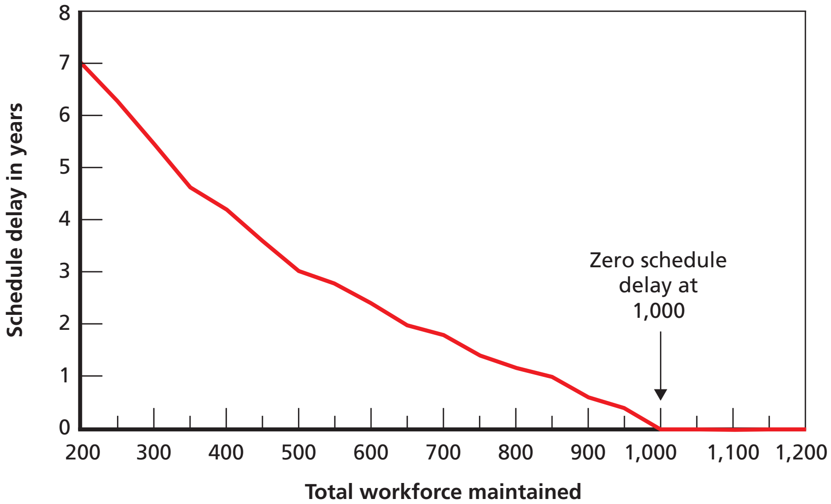

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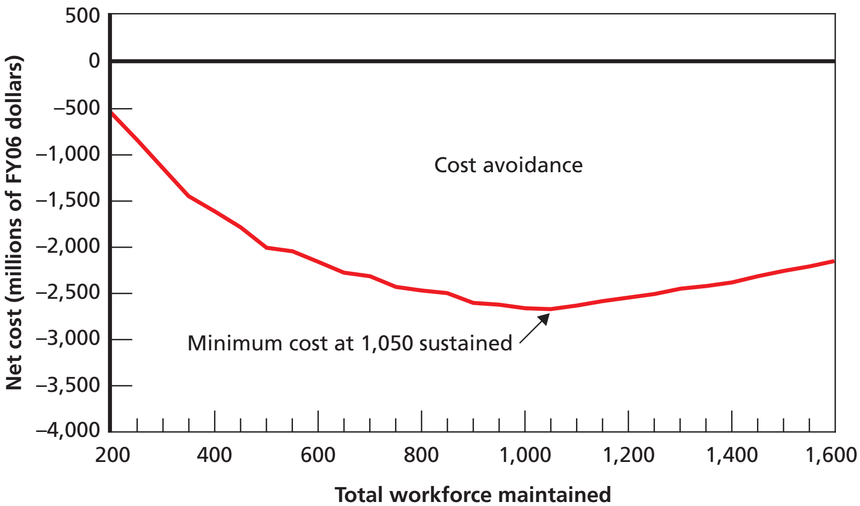
Figure 4.4
Base Case: Cost Impact of Sustaining Various Levels of Design Resources at NGNN



RAND *MG608-4.4*

$2.5 billion less than if no workforce is maintained. As more than 1,050 people are maintained the total cost of labor starts to increase. However, it is still less costly to maintain people than to "do nothing" for all levels of workforce evaluated.

In the case of the minimum-cost solution, approximately 3,000 man-years are required to "fill" the gap at EB, at a cost of approximately $600 million. In the case of the minimum-cost solution at NGNN, approximately 4,000 man-years are required to "fill" the gap at a cost of approximately $900 million. Compared to letting their workforces fall to match the known demands, the cost avoidance of sustaining the least-cost number of designers and engineers is 10 percent in the case where EB accomplishes the total design program and 36 percent if NGNN does the design effort. These various factors are summarized in Table 4.1.

Table 4.1
Base-Case Results

	EB	NGNN
Timing of new start	2014	2014
Duration of design effort (years)	15	15
Magnitude of design effort (million man-hours)	35	35
Least-cost workforce sustained	800	1,050
Man-years in gap	3,000	4,400
Labor cost of gap ($M)	600	900
Cost of gap plus new design for least-cost workforce ($B)	3.5	3.7
Cost of new design under "do nothing" strategy ($B)	3.9	5.8
Labor cost avoidance relative to "do nothing" (cost of gap + new design) (%)	10	36

Impact of Different Design Start Dates

The base-case design start date of 2014 assumes a future SSBN force structure of 14 submarines and a 45-year operational life for the *Ohio* class. If a larger force structure is required or if the operational life of the *Ohio* class is less then 45 years, a new SSBN design effort must begin before 2014. Conversely, if the future SSBN force structure is smaller or if the *Ohio* class has a longer operational life, a new SSBN design effort would start later than 2014. Because of these uncertainties, we next evaluate the impact of design start dates ranging from 2009 to 2018 on the least-cost workforce to maintain at EB and NGNN.

There are many effects that complicate the comparison of estimates across start years. The number of people in the workforce available to mentor new hires decreases as the design start date is delayed, because the amount of work on the books decreases into the future. Therefore, the "do nothing" case becomes more and more costly as the start of the new design is delayed. At the same time, the later the start of the new design, the more expensive it becomes to maintain the workforce.

The least-cost workforces to sustain for various design start years are shown in Figures 4.5 and 4.6 for EB and NGNN, respectively. The least-cost workforce level to sustain during the design gap is fairly constant as the timing of the new start varies. About five percent more designers and engineers are sustained at EB for earlier starts and about five percent fewer for later starts. The pattern is slightly different for NGNN, with the least-cost workforce for early and late starts being slightly less than the workforce for start dates around our base-case assumption of 2014. However, for both EB and NGNN, adjustments to the start date for the next new design have little impact on the least-cost workforce level to sustain. At EB, between 750 and 850 individuals should be maintained, depending upon the start date. At NGNN, between 1,000 and 1,050 people should be maintained, depending upon the start date.

It is important to point out that the insensitivity of the least-cost workforce to sustain does not imply insensitivity of the cost of sustaining the additional workforce until the new design starts. Each year

Figure 4.5
Least-Cost Workforce as a Function of Start Dates: EB

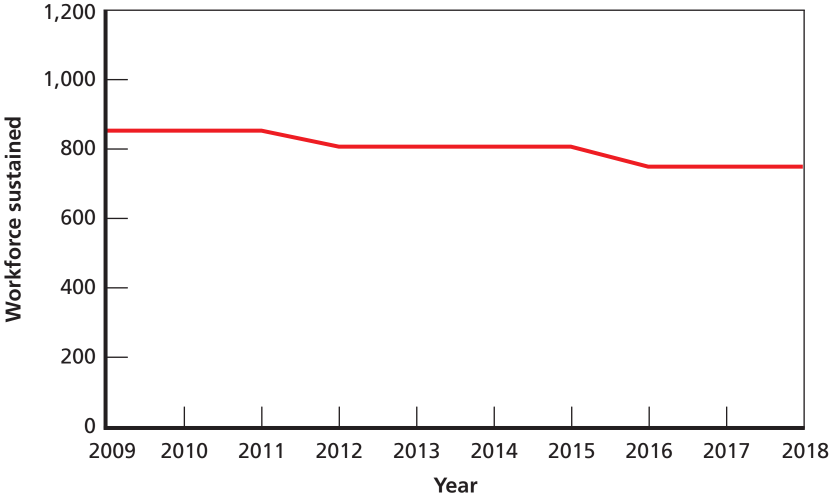


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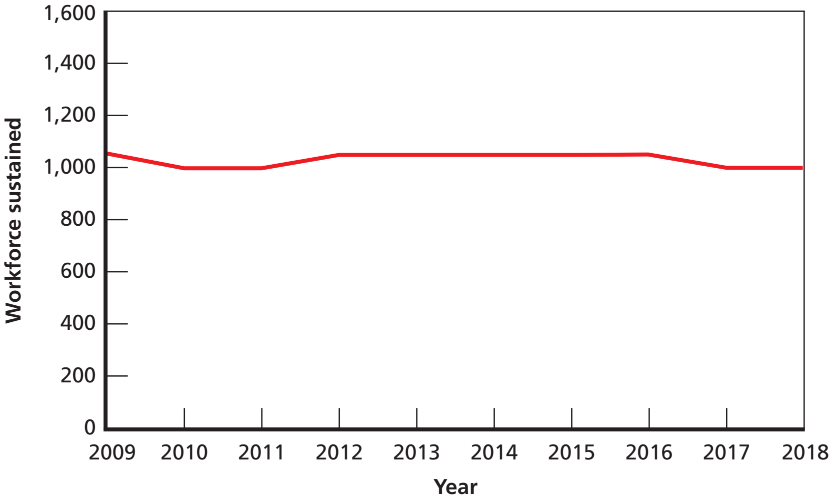
Figure 4.6
Least-Cost Workforce as a Function of Start Dates: NGNN



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of delay in the start date, or each year sooner the new design starts, results in one additional, or fewer, years to pay for the "extra" workforce. For example, at EB, the number of man-years required to fill the gap increases by approximately 500 for every year the design start is delayed, at a cost of approximately $100 million. At NGNN, the man-years required to fill the gap increases by approximately 750 for every year the design is delayed, at a cost of approximately $150 million.

Impact of Different Design Workloads

Until the required capabilities of the next generation of nuclear submarine are established, it is not clear how many man-hours will be needed to accomplish the design program. Therefore, just as we evaluate the sensitivity of the least-cost number of people to sustain and the resulting costs to changes in start date, we also evaluate the sensitivity to changes in required design workload.

The required design workload for a new SSBN class may be greater than that required for the *Virginia* class because of the additional missile compartment requirements of an SSBN. On the other hand, the future design workload may be less than that of the *Virginia* class because of greater efficiency associated with the CAD/CAM design tools or through lessons learned during the *Virginia*, MMP, and SSGN programs.

Figure 4.7 shows the least-cost workforce to sustain for various design start dates and design workloads at EB. In general, for design start dates from 2011 to 2018, the increase or decrease in the least-cost number of designers and engineers to sustain is directly proportional to the increase or decrease in the expected design workload. A 30-percent increase in workload over that for the *Virginia* class design effort results in an increase of approximately 30 percent in the number of designers and engineers to sustain. The same relationship is seen if the future design workload is less than that of the *Virginia* class.

This relationship deviates somewhat for early design start dates. If the new design effort starts in 2009 or 2010, proportionately more designers and engineers should be sustained compared to later start

dates because the current workload at the shipyard supports these workforce levels, and the gap in demand is shallow enough and short enough that it is not economical to let some of those workers go and then rehire them. There is thus almost no need to sustain additional designers and engineers above known work.

Figure 4.8 shows the least-cost workforce to sustain for various design start dates and design workloads at NGNN. The relationship here between the least-cost number of designers and engineers to sustain and the start of the next new design effort is similar to that for EB. If the start of the new design is between 2011 and 2018, the increase or decrease in the least-cost number of designers and engineers to sustain is directly related to the increase or decrease in the magnitude of the design effort: A 30 percent increase in design workload leads to approximately a 30 percent increase in the number of designers and engineers to sustain; a 30 percent decrease in workload leads to a 30 percent decrease in the required workforce to sustain. Also, as with EB, the relationship between the number to sustain and the start date varies more widely for design starts in the 2009 to 2011 time frame—the current work on the books, specifically the CVN 78 design effort, supports a large number of designers and engineers.

How does the least-cost number of designers and engineers to sustain impact the number of man-years and the resulting cost to "fill the gap" for various start dates and design workloads? These values are shown in Figures 4.9 and 4.10 for EB and NGNN, respectively.

Although the patterns are similar, the number of man-years and the resulting cost required to fill the gap at EB is greater than that at NGNN in the early years and less than that at NGNN in the later years. This is because the amount of work at EB is less than that at NGNN in the early years and greater in the out years.

Table 4.2 summarizes our estimates of the impact of sustaining a least-cost design workforce at EB and NGNN for various start dates and new design workload estimates. In all cases, it is less costly to sustain a number of designers and engineers that is at times larger than required to support currently planned demands than to let the workforce fall to match those known demands. The least-cost number varies depending on when the next new design effort might start, the

Figure 4.7
Impact of Various Workloads and Start Dates: EB

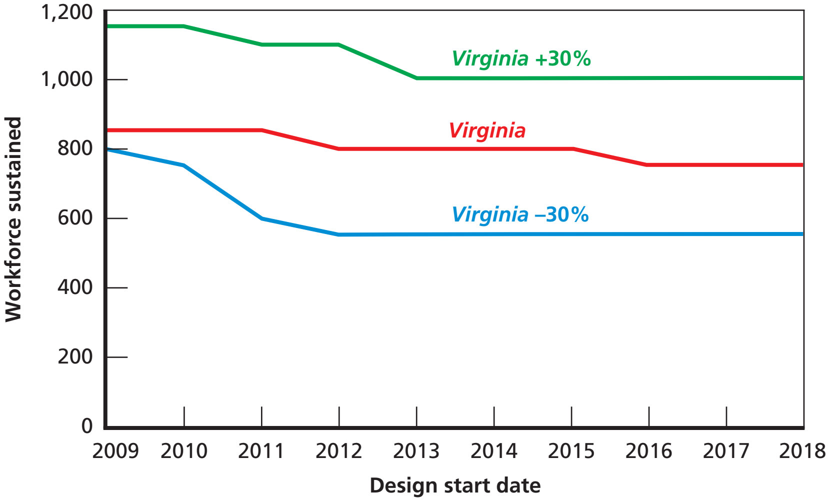

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Figure 4.8
Impact of Various Workloads and Start Dates: NGNN

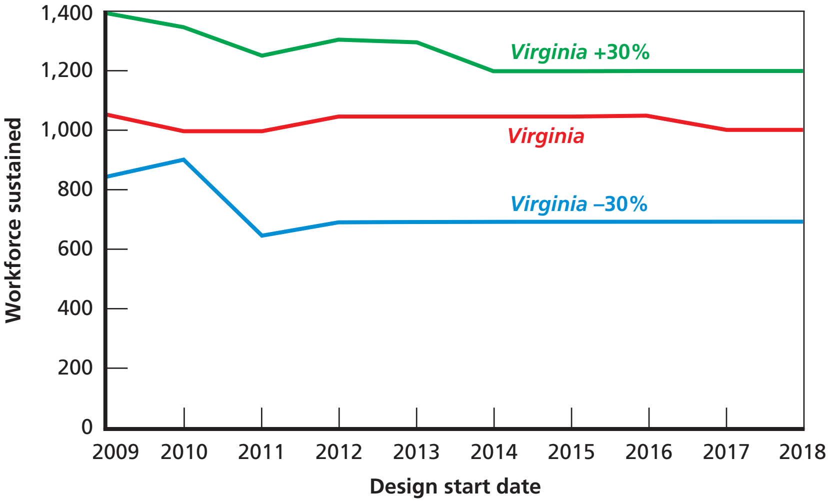

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Figure 4.9
Man-Years and Cost to Fill the Gap: EB

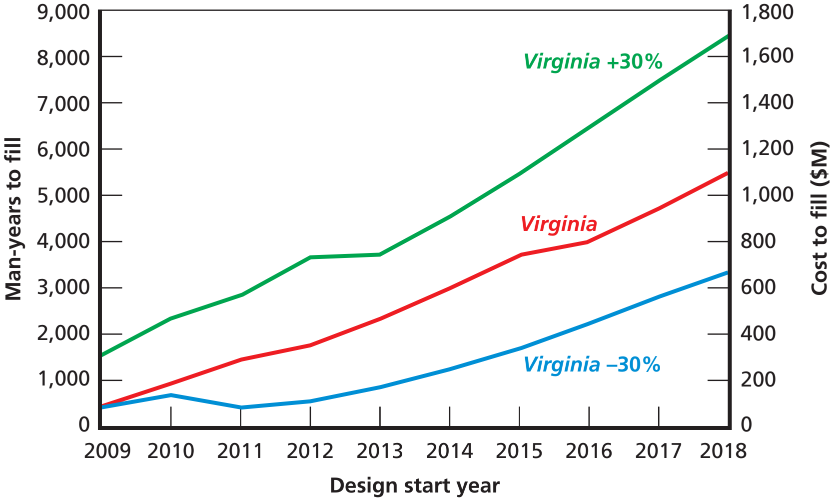

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Figure 4.10
Man-Years and Cost to Fill the Gap: NGNN

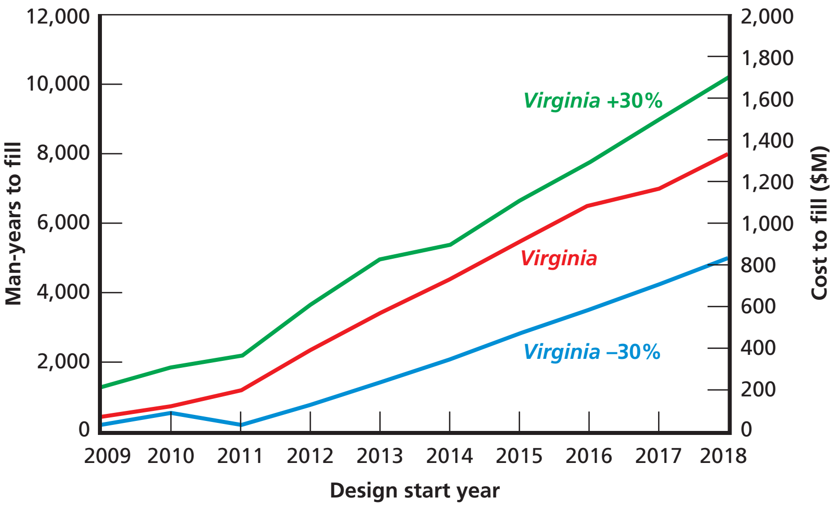

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Table 4.2
Results for –30 Percent to +30 Percent Difference in Design Workload at Different Start Dates

	EB			NGNN		
Timing of new start	2009	2014	2018	2009	2014	2018
Least-cost workforce sustained	800–1,150	550–1,000	550–1,000	850–1,400	700–1,200	700–1,200
Man-years in gap	500–1,500	1,200–4,500	3,300–8,500	200–1,300	2,000–5,500	5,000–10,000
Cost of gap ($M)	90–300	300–900	700–1,600	50–250	500–1,000	1,000–1,800
Cost of gap plus new design for least-cost workforce ($B)	2.2–3.8	2.4–4.4	2.9–5.1	2.2–4.4	2.6–4.5	3.3–5.4
Cost of new design under "do nothing" strategy ($B)	2.2–4.4	2.8–4.9	4.2–7.1	2.3–4.5	4.5–7.1	5.6–10.0
Percentage of labor cost avoided relative to "do nothing" strategy (cost of gap plus new design)	0–14	10–14	28–31	2–17	36–42	41–46

NOTE: Ranges are for –30% to +30% of the *Virginia*-class design workload.

magnitude of the design effort, and the shipyard performing the new design program. For EB, the least-cost workforce to sustain is between 550 and 1,150; for NGNN, it is between 700 and 1,400. Earlier start dates result in extra resources having to be sustained for shorter periods of time, which in turn results in lower costs to fill the gap. Also, current known design work sustains the majority of the designers and engineers during the gap. Later start dates have the opposite effect. Overall, sustaining the least-cost number of designers and engineers can reduce the cost of the next design program by up to approximately 46 percent relative to the cost of letting the workforce fall to match known demands.

The uncertainty of the future start date and workload requirements coupled with the need to take action now to preserve the skills required to design future nuclear submarines requires a sound risk-management strategy. Our analysis shows the least-cost number of people to sustain varies with assumptions about start date and workload, but in all cases, additional meaningful work should be identified and funded for some number of designers and engineers. Funding meaningful work in the short term will lead to lower cost and schedule penalties for the next new design effort compared to not funding activities for additional designers and engineers. Also, starting the next new design effort sooner rather than later will reduce costs and risks.

Implications of a Longer Design Duration

As discussed in Chapter Three, the shipyards are currently working on procedures and processes to plan and execute design work in a new way. Traditionally, there has been a gradual increase in workforce over the first two years of the design effort, then a sharp increase in workforce between years two and six. After peaking for a year or two, the workforce then sharply declines over the next several years. Under a longer design duration, work would be reorganized so that there is a more gradual ramp-up to a peak level that is approximately half of the peak for the 15-year design duration. The peak workforce demand would be maintained for a longer period of time than in the 15-year

design duration case and would be followed by a gradual and shallow decline in the workload at design completion. The green line in Figure 4.11 represents this longer, "level-loaded" approach, and the red line represents the traditional approach.

We make a number of assumptions in evaluating the impact of a stretched design timeline on the cost and schedule of reconstituting the design workforce. First, we assume that the duration of the new design will be approximately 20 years. It is unknown at this time what the exact distribution of skills required to accomplish this new profile will be, so we assume that the distribution of skills is the same as it was for the *Virginia* class. In addition, since we cannot measure how a new design profile will change total workload, we assume that procedures and processes will be in place to mitigate work growth such that the total workload will be the same as that for the *Virginia* class. Finally, we assume a 2029 delivery date, implying a design start date of 2009.

Table 4.3 compares the various measures for the least-cost workforce for a 15-year design and a 20-year design at EB and NGNN. If a level-loaded design is started in 2009, the estimated least-cost workforce is 900 at EB and 950 at NGNN. Very little additional workload

Figure 4.11
Workload Profiles for Level-Loaded and Traditional Design Efforts

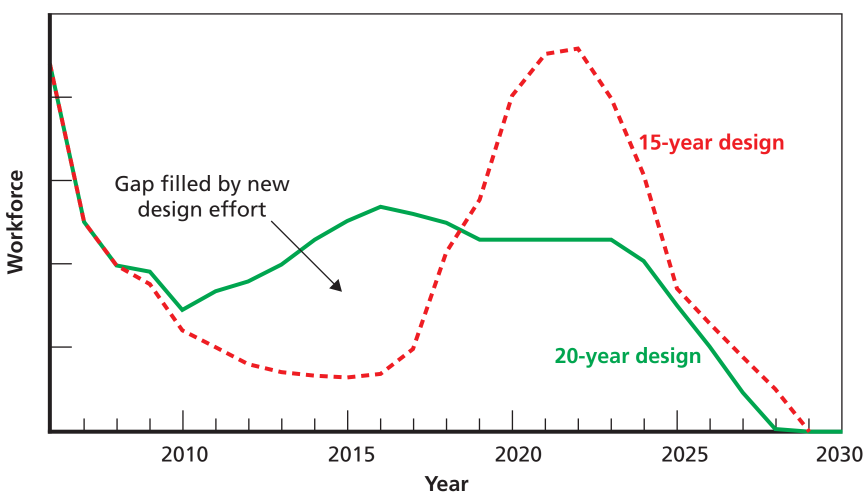

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Table 4.3
Impact of a Stretched Design

	EB		NGNN	
Design duration (years)	20	15	20	15
Timing of start	2009	2014	2009	2014
Least-cost workforce sustained	900	800	950	1,050
Man-years in gap	250	3,000	70	4,400
Cost of gap ($M)	50	600	15	900
Cost of gap plus new design for 20-year least-cost workforce ($B)	2.9	—	2.9	—
Cost of gap plus new design for 15-year least-cost workforce ($B)	—	3.5	—	3.7
Cost of new design under 15-year “do nothing” strategy ($B)	—	3.9	—	5.8
Savings in labor costs relative to least-cost 15-year case (cost of gap plus new design) (%)	17	—	22	—
Savings in labor costs relative to 15-year “do nothing” case (cost of gap plus new design) (%)	26	—	44	—

is required above work that is currently in the shipyard to sustain this level of workforce. To bridge the gap at EB, only 250 man-years are required at a cost of approximately $50 million, and at NGNN only 70 man-years are required at a cost of approximately $15 million. The total cost of bridging the gap and accomplishing the new design effort is at least a half billion dollars less in the 20-year level-loaded option than in the least-cost 15-year profile and one to three billion dollars less than “doing nothing” with a 15-year profile. This implies that a level-loaded design program could incur cost growth of almost those amounts due to additional design work and still be cheaper than the traditional design approach.

In addition to the cost avoidance, the level-loaded design approach has benefits for both industry and the Navy. If a design program is not started until 2014 or later, design work will be required in order

to maintain the least-cost workforce. Although there are a number of potential ways to keep the workforce employed, none will keep the workforce as proficient or experienced as submarine design work.

Implications of Splitting the Workload Between EB and NGNN

The previous analysis assumed that either EB or NGNN would conduct the entire new design effort. Under this scenario, it is likely that the contractor not involved in the new design would completely lose its capability to successfully conduct a new submarine design. If the Navy desires to sustain nuclear submarine design capability at both EB and NGNN, the next new design effort may involve a collaboration between the two organizations. The *Seawolf*-class design effort was a collaboration between EB and NGNN, and EB provides design resources and capabilities to the current CVN 78–class design as a subcontractor to NGNN.

We evaluate several potential work-sharing scenarios, including splitting the work evenly between the two shipyards and implementing a 75/25 split in a "lead-follow" arrangement. We also evaluate splitting the work for both the 15-year and the 20-year design durations. We run the analysis under each of two alternative assumptions: that splitting the design effort between the two shipyards would not lead to an increase in the total design workload and that the split would lead to extra management efforts and inefficiencies that result in a 25-percent increase in the total design workload. Our analysis does not look at how work-packages would be divided or what organizational and procedural arrangements would be required to ensure the success of the split program.

Table 4.4 summarizes the cost differences and variation in least-cost workforce for the various split workload options assuming the design duration is 15 years. If the design is split evenly between shipyards and there is no work growth associated with splitting the design, then a total of 950 people should be maintained between the two shipyards. This is 150 more than if EB alone is awarded the design effort and 100 less than if NGNN alone is awarded the design effort. The

Table 4.4
Summary of Least-Cost Workforce and Cost Growth for Workload Splits: 15-Year Design Duration

Workload Split (EB/NGNN)	Split Penalty (%)	Least-Cost Workforce Sustained	Man-Years in Gap	Cost of Gap ($M)	Cost Growth Relative to Design Done Solely by EB or NGNN (%)[a]	
					EB	NGNN
50/50	0	950	1,900	450	9	3
	25	1,150	2,800	635	37	30
75/25	0	900	2,200	510	9	3
	25	1,100	3,300	730	37	30

[a] For least-cost workforce.

cost of the gap plus the new design effort is approximately 9 percent greater in the case of a 50/50 split than if the design effort is given to EB only and 3 percent greater than if the design effort is given to NGNN only. This increase in cost is because termination costs are included for both shipyards versus for only one shipyard in the case where the total design effort is performed by either EB or NGNN (i.e., we do not account for termination costs at the shipyard that is not doing the design in the case where the total design is accomplished by a single shipyard). The workforce level to sustain, the man-years and cost to fill the gap, and the cost penalties grow if there is additional design workload associated with inefficiencies caused by splitting the design effort between the two shipyards.

If the design workload is split on a lead-follow basis with EB doing 75 percent of the work and NGNN doing 25 percent, the workforce to sustain is less than in the case of an even 50/50 split, but the man-years and cost to fill the gap are more. The cost penalties in the 75/25 lead-follow case are the same as with a 50/50 split in design workload. Therefore, splitting the workload between the two shipyards is more costly than having a single shipyard perform the total design effort, but the increase in cost is less than 10 percent if the design workload does not grow due to inefficiencies arising from a split design effort.

Table 4.5 shows analogous values associated with splitting the workload between the two shipyards for a 20-year design duration. If the workload is split between the two shipyards, both shipyards have sufficient work on the books to sustain the least-cost workforce until the design effort begins. Therefore, there are no additional man-years or costs to fill the gap (except for a very small number of man-years and resulting cost in the 75/25 split with workload inefficiencies resulting from splitting the design). However, if the design duration is 20 years, larger overall costs result from splitting the workload between the two shipyards. Costs increase by 14 to 17 percent if no additional work arises from splitting the design and by 41 percent if the design workload increases by 25 percent because of inefficiencies associated with the two shipyards sharing work on the design.

Sensitivity to Workforce Input Variables

Many of the key input variables described in Chapter Three are estimates provided by the prime contractors. As with many of the other

Table 4.5
Summary of Least-Cost Workforce and Cost Growth for Workload Splits: 20-Year Design Duration

Workload Split (EB/NGNN)	Split Penalty (%)	Least-Cost Workforce Sustained	Man-Years in Gap	Cost of Gap ($M)	Cost Growth Relative to Design Done Solely by EB or NGNN (%)[a]	
					EB	NGNN
50/50	0	N/A	0	0	17	17
	25	N/A	0	0	41	41
75/25	0	N/A	0	0	14	14
	25	N/A	50	10	41	41

[a] For least-cost workforce.

N/A = not applicable; in these cases current design work is sufficient to maintain the least-cost workforce.

variables, there is uncertainty surrounding these estimates. It is possible that market factors could cause attrition, productivity, and hiring rates to be greater or less than expected. To understand the implications of improved or degraded workforce conditions, we evaluate optimistic and pessimistic scenarios. Attrition, productivity, and hiring rates are adjusted simultaneously to establish the aggregate effect of improved or degraded conditions, as shown in Table 4.6.

This range of values is based on reasonable estimates of sustainable rates. For example, although there can be short bursts of hiring when growth rates are high, historical data indicate that this is not sustainable for long periods of time.

The effects of changes to these and other variables will vary depending upon start date and workload size. We first summarize the effects of these cases assuming a 2014 start date and a workload similar to that required for the *Virginia* class. At EB, if attrition, productivity, and hiring rates are as reported, at least 800 people should be maintained. In the optimistic case, 650 designers and engineers should be maintained. In the pessimistic case, a minimum of 1,000 individuals should be maintained. At NGNN, if attrition, productivity, and hiring rates are as reported, 1,050 individuals should be maintained. In the optimistic case, 300 fewer should be maintained, while in the pessimistic case a minimum of 250 more should be maintained.

Figures 4.12 and 4.13 show the net cost of maintaining various levels of the workforce at EB and NGNN respectively. The difference in cost avoidance between the pessimistic case and the expected case is greater than between the optimistic case and expected case because the

Table 4.6
Range of Evaluated Values Around Baseline Estimates

	Optimistic	Pessimistic
Productivity	+0.05	–0.05
Attrition	–0.01	+0.01
Hiring rate	+0.05	–0.05

Figure 4.12
Workforce Parameter Sensitivities: EB

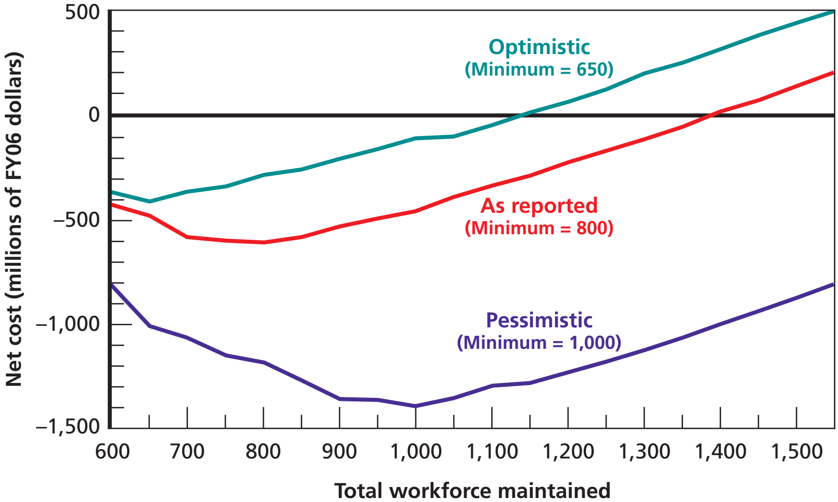

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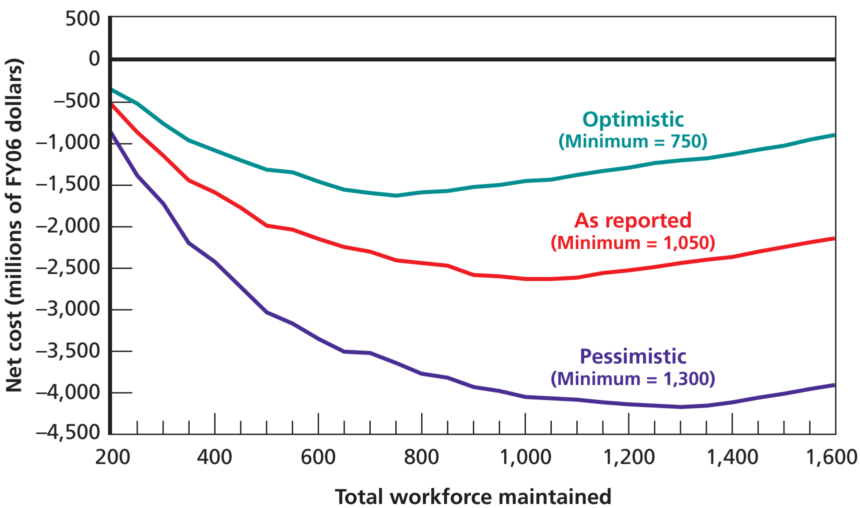
Figure 4.13
Workforce Parameter Sensitivities: NGNN



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penalty of "doing nothing" is more severe in the pessimistic case than in the optimistic case.

As in previous analyses in this monograph, as the start date varies, the least-cost workforce to maintain is fairly stable. This holds true in both the optimistic and pessimistic cases (see Figures 4.14 and 4.15). The least-cost workforce to maintain is a bit higher for early design start dates and a bit lower for later design start dates at EB and more variable at NGNN. At both EB and NGNN, in the optimistic case the least-cost workforce to maintain is approximately 200 people less than the base case and in the pessimistic case, about 200 people more than the base case. For earlier start dates, somewhat more than an additional 200 people should be maintained in the pessimistic case and slightly more than 200 people fewer should be maintained in the optimistic case. For later start dates somewhat fewer than an additional 200 people should be maintained in the pessimistic case, while the number in the optimistic case depends on the shipyard.

Qualitative Impacts of the "Do Nothing" Option

The analysis presented in this chapter so far quantitatively estimates the cost and schedule implications of sustaining a design workforce above known demands compared to those of the "do nothing" option. However, there are a number of qualitative issues surrounding the "do nothing" option that we could not express quantitatively.

Our analysis assumes that at least one of the shipyards chooses to remain in the business of designing submarines. Of course, there is a chance that EB or NGNN, or both, may decide that the uncertainties surrounding future submarine design efforts and the cost of reconstituting their design capabilities are too great to justify expending additional resources to sustain their design capability. Also, we assume that the current design staffs at EB and NGNN would choose to remain, even in light of the instability of their jobs, and that new hires could be attracted to what might be perceived as a troubled industry. If the current designers and engineers at the shipyards do not see a future and leave for other opportunities, valuable experience will be lost and addi-

Figure 4.14
Least-Cost Workforce for Select Start Dates: Optimistic and Pessimistic Scenario: EB

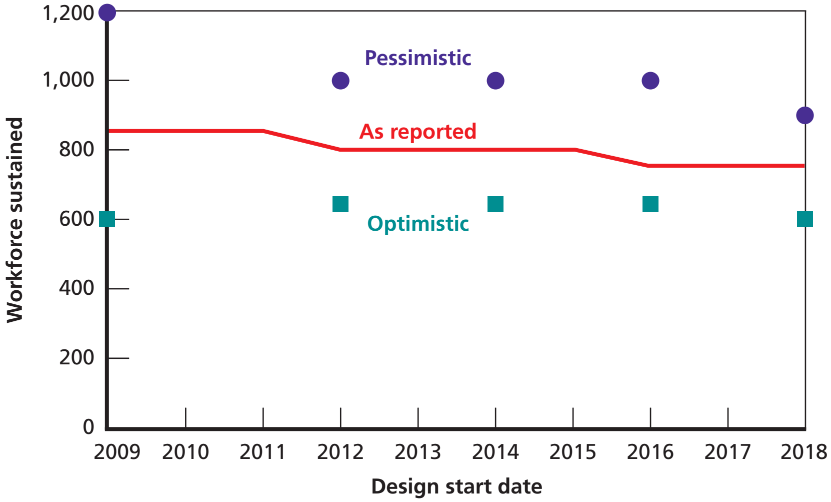

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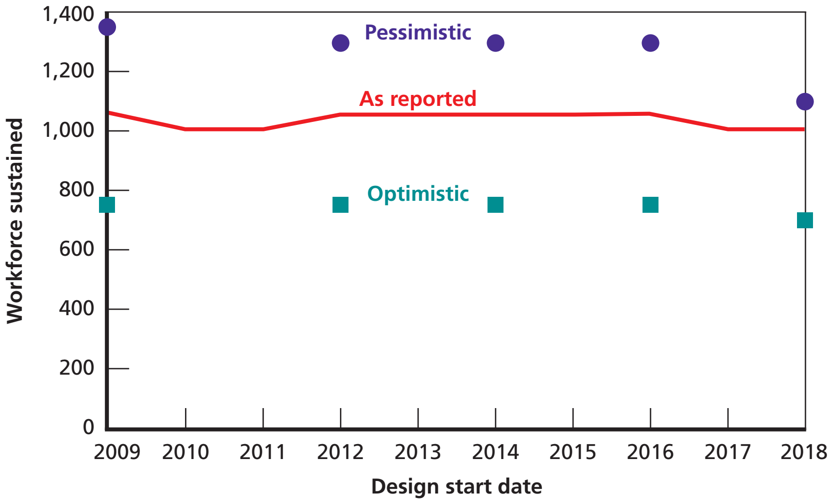
Figure 4.15
Least-Cost Workforce for Select Start Dates: Optimistic and Pessimistic Scenario: NGNN



RAND *MG608-4.15*

tional new hires will be needed. If skilled designers and engineers and new college graduates are not attracted to jobs in nuclear submarine design, it will be even more difficult and costly to reconstitute design workforces at EB and NGNN.

The biggest risk with the "do nothing" option is the loss of valuable, and perhaps irreplaceable, submarine design experience. Experience is necessary to augment the basic knowledge gained through university courses and degree programs. Experience is only gained from having accomplished a task, at times learning from errors that were made. Our models assume this experience is available in the design workforce at the shipyards in sufficient degree to start and lead a new design effort. If experience is lost, risks arise concerning the safety and producibility of a new design. The U.S. Navy's consistent attention to the safety of nuclear submarines and its need to constrain future construction costs suggest that the potential impact of the loss of valuable experience in the design workforce may outweigh the short-term monetary benefits of letting the design workforce decline with demand.

Options for Sustaining Submarine Design Resources[2]

Our findings regarding shipyard workforce management options suggest advantages to sustaining a design workforce in excess of demand, assuming a 15-year design duration. This raises the question of what this excess sustained workforce must do in order to retain its skills. There are several options:

- spiral development of the *Virginia* class
- design of conventional submarines
- design-without-build strategies
- other ship design programs
- collaboration with allies.

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2 This section is largely based on previous research conducted for the UK's *Astute* program. See Schank et al., *The United Kingdom's Nuclear Submarine Industrial Base, Volume 1*, pp. 24–35.

These options are not mutually exclusive and combinations are likely to be required to sustain the full range of technical specialties. None of the options entail the complete design and construction of a submarine. Therefore, the Navy will have to coordinate these efforts with ongoing in-service support and modernization programs to address individual technical areas. Even if fully coordinated with each other and with other efforts, all of the options have drawbacks.

Spiral Development of the *Virginia* Class

Spiral development is a practice commonly used to enhance the performance of production platforms through the incorporation of new technologies or new capabilities that respond to emergent threats or missions. Spiral development also provides an opportunity to examine ways to reduce procurement or operating costs and is an effective method of sustaining design resources between new design programs.

The *Los Angeles* class of nuclear submarines and the DDG 51 class of destroyers are examples of spiral development. Both the *Los Angeles* (SSN-688) and the DDG 51 classes included multiple "flights," or variants, over their 20-year construction periods.

The length of the *Virginia*-class construction program suggests that upgrades will be necessary. The current shipbuilding plan calls for construction to continue through 2020. Currently, sonar, combat, and communications systems are in de facto spiral development. The introduction of commercial-off-the-shelf (COTS) hardware and the Advanced Processor Build and Acoustic Rapid COTS Insertion programs have separated nonpropulsion electronics from new submarine design programs. As a result, those technical communities will not be significantly affected by the upcoming design gap. In an effort to reduce the procurement costs of the *Virginia* class, the Navy has begun a cost-reduction effort that can be properly viewed as a spiral development program.

Spiral development, while an effective tool to assist in maintaining the core personnel, cannot sustain the entire range of technical specialties. Previous upgrades have focused on propulsion, combat systems, and discrete hull systems. Rarely does a class upgrade address the basic hull form or mechanical arrangements. In order to sustain the

Navy's entire submarine design community, it must supplement spiral development with activities that address areas that spiral development will not affect. Additionally, the Navy must specifically include funding within those upgrade programs for the naval warfare centers. For example, SSN 23 was a significant spiral based on the *Seawolf* class that contributed only $3 million to $5 million per year to the Navy's HM&E community at the Naval Surface Warfare Center's (NSWC's) Carderock Division.

Design of Conventional Submarines

The design of conventional submarines, either for the U.S. Navy or for sale to foreign nations, could sustain all skills necessary for submarine design save nuclear skills. However, there are several conditions that make this option unattractive. The current export market for conventional submarines has several sellers but few buyers. Germany, Russia, Spain, and France, often through collaborative efforts, have several conventional submarine designs available for sale. Several countries have purchased conventional submarines, including China, Greece, and India, but many conventional submarine buyers are turning to their own indigenous designs. A U.S. entry into the conventional submarine market might only succeed if there were a dedicated buyer, such as Taiwan.

More importantly, a new class of submarines must be inexpensive if it is to compete in the marketplace. The ingrained mindset of safety and redundancy associated with U.S. nuclear submarines and their more stringent operational environments would be difficult to overcome, potentially leading to added costs. Conventional submarine designs from EB and NGNN may be too costly and complex for foreign buyers. Finally, the U.S. government may not allow the export of sensitive technologies.

Design Without Build

Design without build refers to the practice of conceptual design efforts and can complement spiral development. As opposed to exercising skills typically involved in spiral development, conceptual designs can focus on new hull forms and mechanical and electrical system arrange-

ments. Conceptual designs allow naval architects and acoustical engineers to consider innovative designs without the expense of actually building the submarine. These design efforts form the basis for subsequent new submarine design programs. Germany, for example, funds new submarine design efforts every six years; many of the designs do not advance to the construction stage. These conceptual designs can be supplemented by including scale model testing at NSWC's Acoustic Research Detachment in Bayview, Idaho.

The main disadvantages of design-without-build strategies are the small scale of the projects and the lack of construction and operational feedback to the engineers. Typically, a conceptual study team is small, on the order of 25 to 50 individuals. In order to be an effective tool for maintaining the core technical group, a design-without-build program must be combined with significant spiral development efforts. In addition, designs that are not meant to be built often lack the design discipline and risk management that accompany designs meant for construction. Of course, that is often the purpose of a conceptual design—to explore innovative concepts that would be too risky to build. Finally, the designers lose lessons learned from construction and will not get feedback from the testing of new designs. In both spiral development and design without build, the whole-ship integration skills critical to the successful completion of a new submarine design will not be directly challenged.

Other Ship Design Programs

Many skills used during submarine design are common to surface ship design efforts, and employing submarine designers at EB and NGNN on surface ship design programs would help sustain their capabilities during a gap in nuclear submarine design. In fact, the majority of the submarine designers and engineers at NGNN are involved in the design of the CVN 78 class of aircraft carriers, and EB is helping NGNN with that design effort. EB engineers are also supporting DDG 1000 design efforts at Bath Iron Works. These surface ship programs represent a large part of the design work currently on the books at EB and NGNN.

However, the CVN 78 and DDG 1000 design efforts will wind down before a new submarine design program would commence in 2014. And, there are no new surface ship design efforts planned for the next several years, except for possibly a new CG(X) evolving from the DDG 1000 class. Therefore, there may not be the opportunity to use EB and NGNN submarine designers and engineers on surface ship programs during a gap in submarine design efforts.

Collaboration with Allies

Collaborative design efforts with an ally, most likely the United Kingdom, may occur in the future. Such collaborative efforts would involve nuclear submarine designers and engineers from one country working with design teams in the other. In fact, the UK's *Astute* design program involved a collaboration between EB and BAE Systems, with EB providing various personnel and services to BAE System's Barrow shipyard design team to help finalize design drawings.

Collaboration has several advantages and several disadvantages. It could help sustain a core of designers and engineers in each country by providing meaningful design work during gaps, especially if new design efforts in the two countries do not overlap. Collaborative efforts could draw on the best resources from both countries and inject new ideas and methods into the design process. Finally, collaboration could help aid the interoperability of the two nations' submarine forces.

However, design programs in the two countries would have to be coordinated so that they occurred sequentially and not concurrently. Concurrent design efforts would require full design teams in each country, unless both countries agreed to a common design. Also, concurrent efforts could lead to subsequent nuclear submarine design gaps in both countries, presenting the exact problem that the collaboration was intended to solve. Collaboration on nuclear submarine design efforts would also require a high degree of technical interchange and a sharing, to some degree, of proprietary, intellectual, and classified information. Establishing the boundaries and ground rules for sharing such sensitive information may be the biggest hurdle to overcome in a collaborative environment.

A collaboration between two countries on nuclear submarine design could be set up in a number of ways. In the most likely case, each country would maintain some level of all design skills and use those design resources to supplement each other for new design programs. In this case, each country maintains the breadth but not the depth of skills needed for a new design program. Another alternative is for each country to maintain only certain design skills and provide them to the other country when needed. In this case, each country maintains depth across several skills but not breadth across all. Finally, a collaborative model could involve each country maintaining a low level of all skills with some critical ones maintained at a higher level, much like when EB provided certain design skills to augment the design team at Barrow.

There are many issues to be resolved in any collaborative model. In addition to the exchange of sensitive information, the two countries would have to decide on whether design teams would be centralized or decentralized and whether both countries would adopt a common computer design tool.

Timing between the next new design effort in the U.S. and that in the UK will be the most important determinant of whether collaboration could be an effective way to sustain design resources. The UK is currently deciding if it will develop a new underwater strategic deterrent system to replace its current *Vanguard*-class SSBNs. If the decision is made to not replace the *Vanguard*-class boats, the UK will not have a new submarine design program for over a decade, if ever. If a new SSBN class is needed, the design effort would have to start very soon to replace *Vanguard*-class boats as they retire from the inventory. The start of design for a new UK SSBN class could fill the U.S. design gap resulting from a 2014 start of the design to replace the *Ohio* class. Also, those collaborating on the next new SSBN design for both countries could share in ideas and technologies.

Summary and Conclusions

Our analysis suggests one major conclusion: It is less costly to sustain some number of designers and engineers above the currently planned design work than to let workforce levels drop to match known demands. The least-cost number of designers and engineers to sustain varies based on assumptions concerning the start of the next new design, the duration and level of effort, and which shipyards conduct the design. But, "doing something" is always less costly than "doing nothing."

If the next new design effort starts in 2014 (as suggested by current planning documents) and has a duration and workload similar to the design effort for the *Virginia* class, the least costly option at EB would be to sustain a minimum of approximately 800 designers and engineers. Sustaining this level would cost approximately $600 million but would reduce the total design costs through the completion of the new design by 10 percent compared with the option of letting workforce levels fall to meet demands. If NGNN conducts the next new design effort, it should sustain a minimum of approximately 1,050 designers and engineers. Sustaining this level of resources would cost approximately $900 million but would reduce total costs through the completion of the next new design by approximately 36 percent compared with NGNN keeping workforce levels equal to known demands.

The least-cost workforce to sustain is fairly constant for new design starts between 2009 and 2018 at both EB and NGNN. Of course, the number of man-years and resulting cost of the "extra" workforce in the gap decreases for earlier start dates and increases as the length of the gap grows. In general, the change in the minimum number of design resources to sustain at both shipyards is roughly proportional to the change in the expected magnitude of the next new design effort—a 30 percent increase in design workload leads to a 30 percent increase in the least-cost workforce to sustain and vice versa.

Because of the high costs of sustaining extra designers and engineers until a 2014 design start, the best option may be to stretch the design effort by five years. A 20-year design effort would start in 2009 and keep the delivery of the first of the new class in approximately 2029. If the total workload of the new design effort does not grow due to inef-

ficiencies associated with the longer design duration, the total costs through the completion of the next new design effort would decrease by 17 percent (compared to the least costly 15-year design duration option) if EB does the next design and by 22 percent if NGNN does the next new design. The longer design profile requires funding of less than $50 million to fill the gap between now and 2009. In essence, at both EB and NGNN, the workforce would transition fairly smoothly between currently known work and the new design effort.

Splitting the next new design effort between the two shipyards would lead to higher costs than assigning all design work to one shipyard, regardless of the percent split between the two shipyards. However, if the total workload does not increase due to inefficiencies of splitting the workload, the total cost of a 75 percent EB, 25 percent NGNN design effort would increase by only 9 percent compared to EB doing the total design for the 15-year design duration and by 14 percent compared to EB alone for the 20-year design duration.

It is important to recognize that the less costly alternatives—sustaining a workforce in excess of demand or, preferably, extending the design period to 20 years—have nontrivial drawbacks that are not easily quantified. Sustaining a workforce in excess of demand raises the question of what the excess workers are to do to maintain their skills. There are several options available that address aspects of the problem, but even if combined and coordinated with other activities, these options may not keep skilled personnel from leaving or sustain the skills of those who stay as well as design work on a new submarine class would. Extending the design period to 20 years raises various risks, such as those of increased overhead and design obsolescence by the time the first of class takes to sea. Of course, “doing nothing” risks the loss of key submarine design skills.

CHAPTER FIVE

Critical Skills

Chapter Four identifies the number of designers and engineers to sustain in order to minimize the cost and schedule of a new design effort. Our analysis is focused at the aggregate level, grouping all designer skills together and all engineering skills together. In this chapter, we disaggregate the designer and engineer groups into the specific skill categories described in Chapter Two.

Ultimately, both EB and NGNN must decide exactly which designers and engineers to sustain within each skill category. These specific decisions should be based on the technical skills and competencies and the experience of the various individuals that make up each organization's design and engineering workforce.

We base our estimate of the number of specific designer and engineering skills on historical data and on the inputs of the two shipyards. However, the technical requirements of future submarines may lead to a different mix of skills than were utilized on past programs. Also, other factors, such as the demographics of the workforce in each skill category and the ability to hire new designers and engineers when rebuilding the workforce, should enter into decisions concerning how many people to sustain in each skill category during the gap.

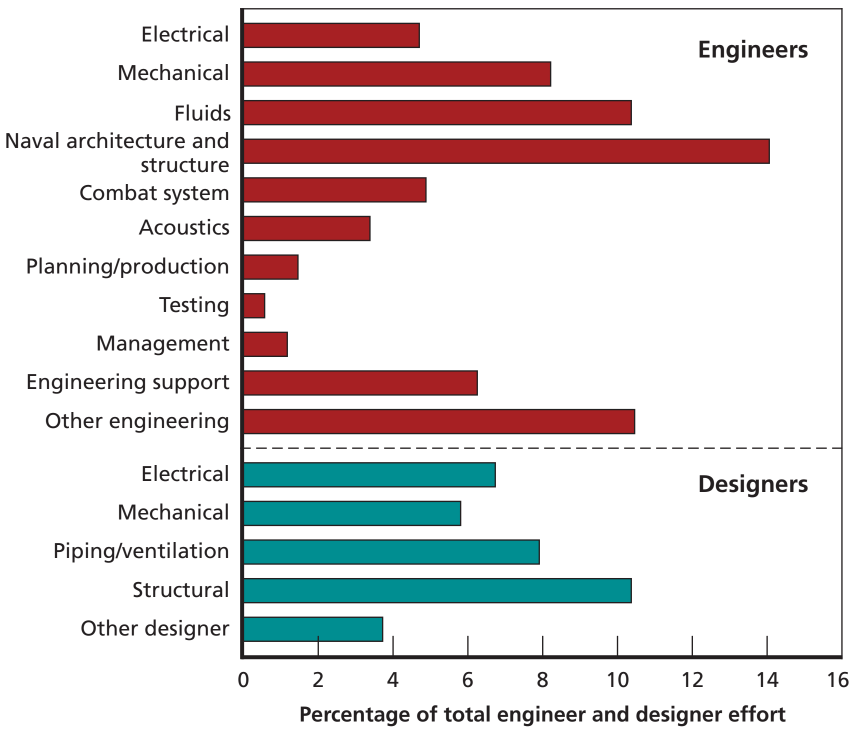
How Many People in Each Skill Category Should Be Maintained?

To identify the number of people required in each skill category, we began with a distribution of skills for each shipyard. For EB, we took

the distribution of skills required for the *Virginia*-class design program, shown in Figure 5.1. NGNN provided an estimated distribution of the engineering and designer skills required for a new design effort, as shown in Figure 5.2. The NGNN distribution differs from that of EB, since each company employs skills in a different manner.

We used the EB and NGNN distributions to estimate how many of each specific skill should be sustained during the design gap. Table 5.1 shows the resulting distribution of designer and engineering skills for EB and NGNN for the base-case assumptions of a 2014 start with a duration (15 years) and workload (35 million man-hours) similar to that required for the *Virginia* class.

Figure 5.1
Proportion of Total *Virginia*-Class Design Effort in Each Skill Category: EB



SOURCE: General Dynamics Electric Boat

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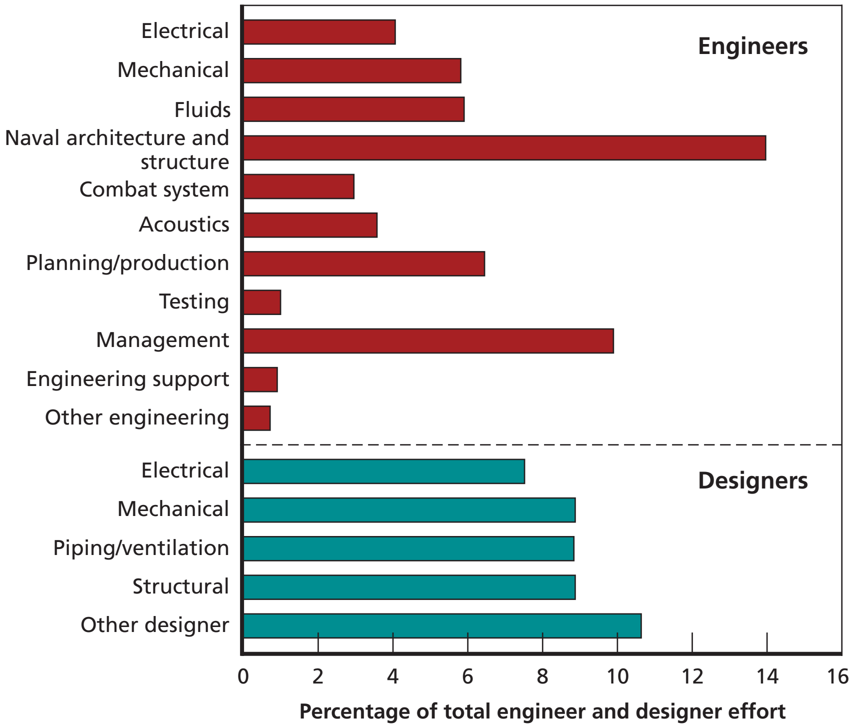
Figure 5.2
Proportion of Total New Submarine Design Effort in Each Skill Category: NGNN



SOURCE: Northrop Grumman Newport News
RAND *MG608-5.2*

Factors to Consider When Deciding How Many of Each Skill Category to Sustain

Table 5.1 suggests the number of designers and engineers in each skill category that EB and NGNN should sustain during a gap in new submarine design efforts based on historical experience. However, a variety of factors must be considered when deciding on the number of

Table 5.1
Number of Designers and Engineers to Sustain, by Skill Category

	EB Base Case (n)	NGNN Base Case (n)
Designers		
Electrical	60	80
Mechanical	50	95
Piping/ventilation	65	95
Structural	80	95
Other	35	115
Designer subtotal	290	480
Engineers		
Electrical	40	40
Mechanical	65	60
Fluids	80	60
Naval architecture and structures	110	145
Combat systems	40	30
Acoustics	25	40
Planning/production	10	60
Testing	10	10
Management	10	105
Engineering support	50	10
Other engineering	80	10
Engineering subtotal	520	570
Total designers and engineers	810	1,050

designers and engineers to sustain in each of the 16 skill categories, including

- The technical specifications of the next submarine design. Any number of technical requirements can change the mix of skills required to design the next submarine. For example, an all-electric submarine will require more electrical and fewer mechanical engineers.
- Workforce demographics. A combination of experience and leadership is required if the design base is to be kept healthy. However, skill categories should not include all senior people with an age distribution such that many would retire before the next new submarine design program starts. To ensure skills are not lost through retirement or attrition, each skill category should include a range of different age and experience levels.
- Ability to find skills outside the nuclear submarine industry. Certain skills may be exercised in nuclear submarine design only. If these skills are lost, reconstitution will be more challenging than for other types of skills that are available from other, non-submarine programs.
- Time to gain proficiency. Skills that take a particularly long time to develop (because they require a great deal of either formal education or occupational training time) are also more challenging to reconstitute than skills that take less time to develop.
- Supply and demand factors. These may affect the availability of certain skills or the ease with which individuals with particular skills can be attracted to the industry.

Technical Specifications

Meeting the technical specifications of future submarines could require a different mix of skills than those used on previous submarine design programs. A survey of potential technology advances for the next submarine design effort reveals that the types of skill categories already identified are not expected to change; the same generic 16 skill categories will be required for the next design effort. However, design teams for the next new submarine may require fewer of some skills and more

of others compared to the numbers of each skill category used in historical design programs. Or, future technologies may require new skill competencies not needed in past programs. Table 5.2 summarizes the expected potential emergent technology changes and the impact on submarine design skill categories.

Anticipating future technical requirements is an important part of workforce planning. Considering the potential future technical requirements of a new submarine design, it is possible that more electrical engineers, electrical designers, naval architects, structural engineers, and structural designers will be required than was the case in

Table 5.2
Impact of Potential Future Technical Requirements on Skill Base

Potential Emergent Changes	Primary Skills Impacted	
	More People Required	Fewer People Required
Acoustic advancements/ reduced signatures	Acoustics/fluids engineers	
Alternative hull forms/hull flexibility	Naval architects, structural and fluids engineers/ designers	
Increased automation	Automation engineers	
Composite advanced sail	Naval architects, structural and fluids engineers	
Composites/advanced materials	Composites/advanced materials engineers	
Electric drive/electric actuation systems	Electrical engineers and designers, power systems engineers	Mechanical, fluids, piping engineers/designers
External weapon stowage	Electrical and electromechanical engineers	Internal weapon stowage/ handling engineers
Increased payload	Naval architects and structural engineers	
Integrated power systems	Electrical and power-systems engineers	
Mother ship/adjuvant vehicles	All	

previous programs. There are also skills that are not currently prevalent, if present at all, in the engineering and design workforce at the shipyards, but may be required in the future. These skills include automation engineering and composites and advanced materials engineering. As demand for these existing skills, or for new skills, grows, the demands for other skills may decrease. For example, transitioning to an all-electric submarine would require fewer mechanical designers and engineers.

Workforce Demographics

In certain skill areas, the workforce is skewed toward older age categories, with many in the current workforce nearing retirement age. Although there is a healthy age distribution among the designer skill categories at NGNN, nearly half of EB's workforce in all designer skill categories is over the age of 50. Certain engineering skill categories are cause for concern at one shipyard or the other. At NGNN, about half the planning and production workforce is over 50, as shown in Figure 5.3. In EB's engineering workforce, only 25 percent of those in combat systems integration and only 16 percent of those in testing are 40 or under. Roughly 65 percent of EB's engineering support workforce is over age 50. Figures 5.4, 5.5, and 5.6 illustrate these distributions.

It is clear that certain skill categories face the possibility of a severely diminished workforce in the near future, and efforts must be taken to replenish and retain workers in these areas. The shipyards should strive for a distribution of ages across the specific people they sustain within each skill category. There needs to be a set of very experienced, and presumably older, individuals that can help guide the workforce through the design gap and, if still in the workforce after the gap, act as the senior managers and mentors when reconstituting the design workforce. But, the shipyards should also sustain a number of designers and engineers in the middle and junior age and experience brackets during a design gap. Union rules may make it difficult to keep younger designers and engineers with less seniority, but sustaining a set of designers and engineers in a skill category that may retire before the next new design effort begins will make it more difficult and more costly to reconstitute the design workforce after the gap.

Figure 5.3
Age Distribution of Planning and Production Engineers: NGNN

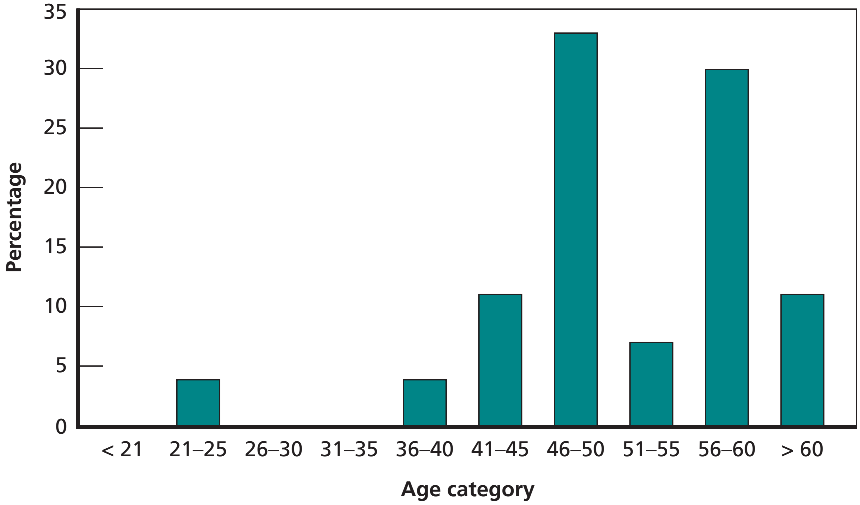


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Figure 5.4
Age Distribution of Combat Systems Integration Engineers: EB

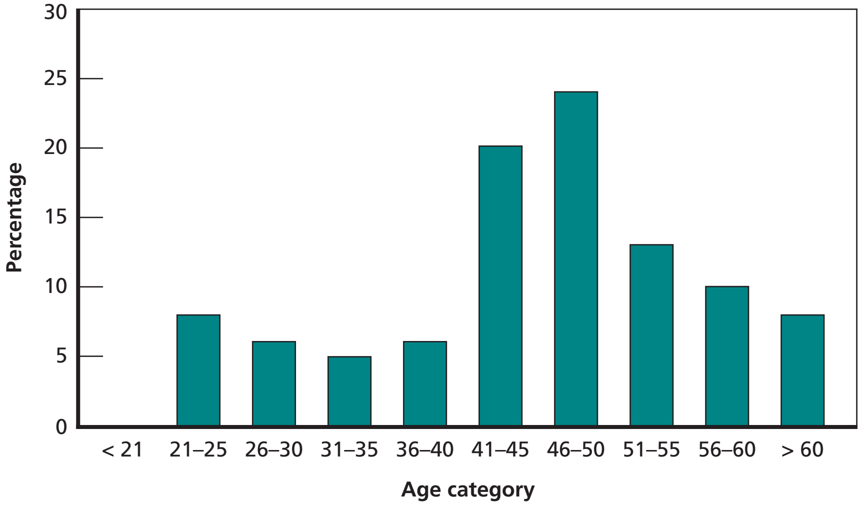

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Figure 5.5
Age Distribution of Testing Engineers: EB

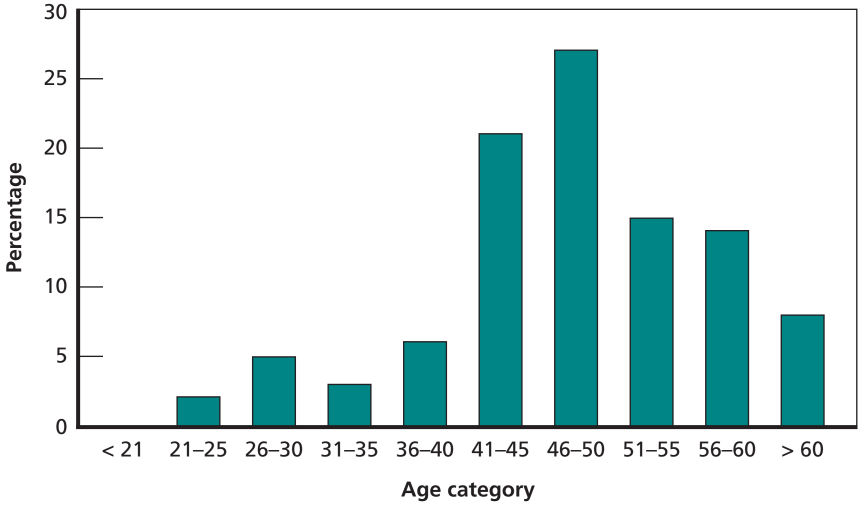

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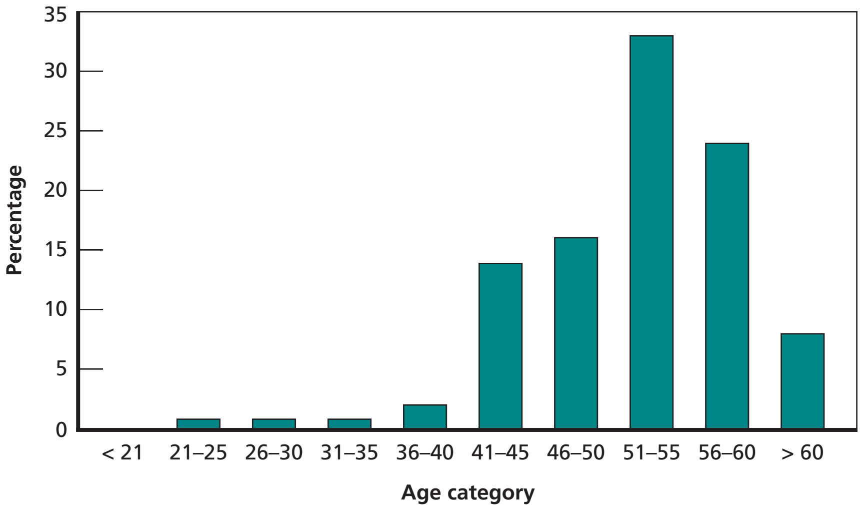
Figure 5.6
Age Distribution of Engineering Support: EB



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Submarine-Specific Skills

Many of the skills used in nuclear submarine design are specific to the nuclear submarine design industry and are not utilized by other ship design programs. For example, the demand for acoustics and nuclear propulsion skills comes primarily from new submarine design programs, while skills associated with the Submarine Safety Program are supported only by new and in-service submarine programs. Other skill categories, although utilized by non-submarine design programs, require special technical competencies in submarine design. For example, there is a distinction between a submarine naval architect and a surface ship naval architect, or a submarine structural engineer and a surface ship structural engineer. Although it can be argued that submarine experience is required to refine and develop submarine-specific skills in all skill categories, there are particular skills that are not exercised outside of a submarine design program. These are the skills that would be the most difficult to reconstitute after a gap in new submarine design programs. EB and NGNN identified 14 submarine specialties not utilized by other types of ship design programs to the degree they are utilized by a new submarine design effort (see Table 5.3).

The submarine-specific skills that are not exercised in other ship design programs tend to be highly technical skills, such as acoustics, silencing, and shock. Though these trades are employed in surface ship design programs, the knowledge that a submarine hydrodynamics engineer and a surface ship hydrodynamics engineer must possess differs. This submarine-specific knowledge can be gained only through submarine industry experience, and, as such, these skills should be managed more closely than others. The best way to mitigate the risk of losing these capabilities is to ensure appropriate design work exists to keep workers with these skills proficient and to ensure new hires gain the necessary submarine experience to become proficient in these skills by the time the next design effort gets under way.

Time to Gain Proficiency

EB's evaluation of the 639 technical competencies required for a submarine design effort indicates that nearly 40 percent require at least five years of experience to develop. Other competencies take more than

Table 5.3
Submarine Specialties and Associated Skills

Submarine Specialty	Skill Categories Affected
Acoustics and silencing	Acoustics/signal analysis
Arrangement density	Structural engineering
Atmosphere control	Other engineering
Design for depth—deep submergence scope of certification	Multiple skill categories
Design for production practices	All skill categories
Hydrodynamics	Naval architects, mechanical engineers, fluid engineers
Nuclear propulsion systems	Nuclear engineering and design
Piping systems	Piping design, structural and arrangement engineering
Pressure hull design	Structural engineering
Ship control systems and powering	Naval, mechanical, electrical engineering
Shock	Structural engineering
Sub combat and weapons systems/ torpedo handling, launch and tube design and engineering	Combat systems engineering; mechanical, structural, and other engineering
Safety	All skill categories
Weight engineering	Fluids, mechanical design/engineering

ten years of experience to develop or more than a bachelor's degree—10 percent require both. Five competencies require at least a master's degree and ten years of experience to develop:

- Computational Structural Mechanics
- Engineering Software Development and Maintenance
- Computational Hull Design and Analysis
- Computational Shock Analysis
- Computational Structural Acoustics.

All of these competencies reside in the Structural Engineering skill category. The most challenging competencies to replace would be those that require at least ten years of experience and a Ph.D. There are two skill competencies that fit into this category: Computational Fluid Dynamics Code Development and Turbulence Modeling. These competencies reside in the Acoustics and Fluids Engineering skill categories.

EB's evaluation helps to provide an indication of the quantity and level of experience required of the design and engineering workforce. If the availability of these skills is negatively affected by a design gap, it would take a number of years of design work to reconstitute them, assuming there are mentors available.

Supply and Demand Factors

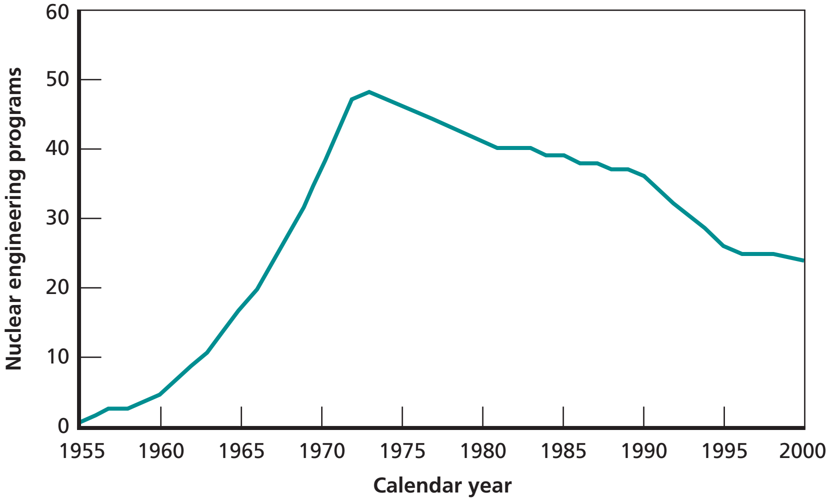
Complicating the issue of reconstituting the submarine design workforce after a gap in design workload demand are the recruiting challenges faced by the shipyards. First, limitations exist as to the number of recruits available for shipyards to hire. Although the number of graduates with engineering degrees is increasing,[1] this is not always the case within maritime-specific engineering disciplines. For example, there are only six non-military schools offering degrees in naval architecture and marine engineering, disciplines critical to submarine design. Furthermore, this problem is particularly prevalent in the nuclear engineering discipline. The number of nuclear engineering programs has been steadily decreasing over the last thirty years, as has the number of nuclear engineering enrollments at universities (see Figures 5.7 and 5.8). The Nuclear Energy Institute has projected a decrease in the supply of nuclear engineers, amounting to more than 50 percent between 2002 and 2011.

High demand for skilled workers in this declining recruitment pool and the resulting competition for graduates further compound the issue. The 1990 and 2000 censuses indicated that science and engi-

---

[1] According to the American Society for Engineering Education, in the 2003–2004 academic year, the number of bachelor's and master's degrees in engineering increased for the fifth consecutive year. Doctoral degrees grew at the fastest rate, with a 6.5 percent increase from 2003 to 2004 and an increase of 35.1 percent from 2001 to 2004.

Figure 5.7
History of Nuclear Engineering Programs at U.S. Universities



SOURCE: Michael L. Corradini, Marvin L. Adams, Donald E. Dei, Tom Isaacs, Glenn Knoll, Warren F. Miller, and Kenneth C. Rogers, "The Future of University Nuclear Engineering Programs and University Research & Training Reactors," draft research paper, prepared for the U.S. Department of Energy, May 10, 2000.
RAND *MG608-5.7*

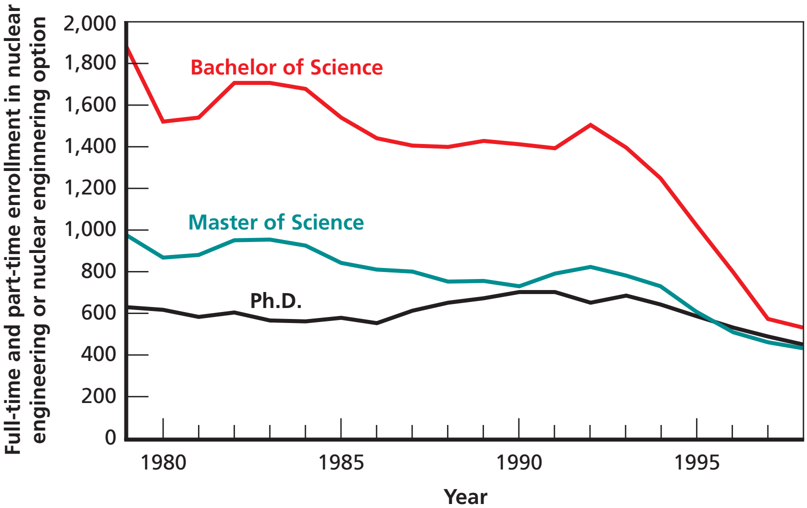
neering occupations grew at an average annual rate of 3.6 percent, more than triple the growth rate of other occupations.[2] An increase in the number of science and engineering jobs makes it more difficult for the nuclear submarine industry to compete for new graduates. This is exacerbated by the anticipated future growth of the nuclear power industry. The Department of Energy forecasts that U.S. electricity demand will increase 50 percent by 2025 and that hundreds of new power plants will be needed to meet this rising demand.[3] Furthermore, the Bush administration is calling for "the expansion of nuclear energy in the U.S. as a major component of our national energy policy."

---

2 "Occupations" refer to job slots, not employed personnel. National Science Foundation, Science and Engineering Indicators 2006, www.nsf.gov/statistics/seind06.

3 U.S. Department of Energy, "Advanced-Design Nuclear Power Plants," fact sheet, April 2005.

Figure 5.8
Nuclear Engineering Enrollments at U.S. Universities



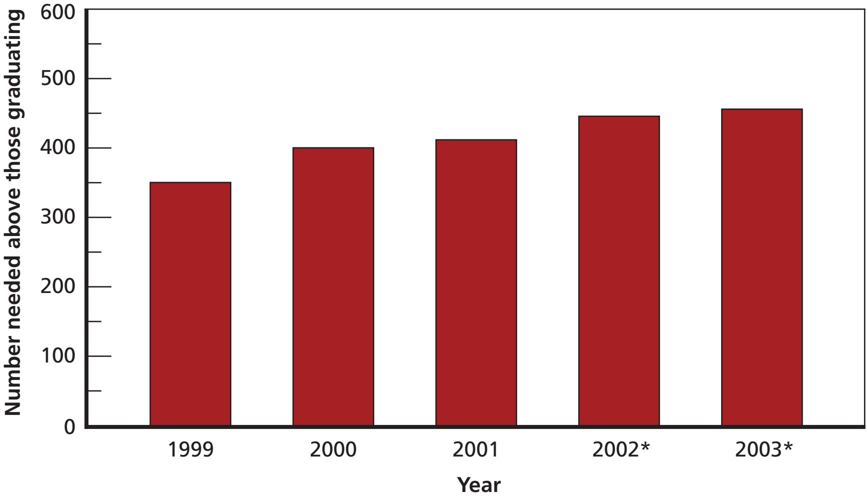
SOURCE: Oak Ridge Institute for Science and Education, "Nuclear Engineering Enrollments Decreased at All Levels in 1998," U.S. Department of Energy Manpower Assessment Brief No. 44, May 1999.
RAND *MG608-5.8*

Low unemployment rates for those with doctoral degrees in science and engineering confirm the existence of a supply/demand gap at this skill level. The National Science Foundation reports that unemployment rates for U.S. doctoral scientists and engineers have remained low over time, diminishing the pool of individuals with relevant doctoral degrees looking for work from which the nuclear submarine industry can hire.

There is strong evidence that the growth in the demand for certain engineering fields will continue to outpace supply. Certainly, this issue is more problematic in disciplines where the gap between demand and supply may be wider and competition is fiercer. Figure 5.9 illustrates how the gap between supply of and demand for nuclear engineers is increasing.

Thus, a potential future shortage of persons with nuclear skills relative to the demand for them may lead to an inability to hire new recruits into the nuclear submarine industry. It is clear that, across dis-

Figure 5.9
Gap Between Bachelor and Master of Science Annual Employment Needs and Students Graduated: For the Fission Nuclear Power Industry



* 2002 and 2003 supply projected at maximum for 1999–2001
SOURCE: American Society for Engineering Education, "Survey of Manpower Supply and Demand in the Nuclear Industry," in Gary S. Was and William R. Martin, eds., *Manpower Supply and Demand in the Nuclear Industry*, Nuclear Engineering Department Heads Organization, 1999.
RAND *MG608-5.9*

ciplines and skill levels, the nuclear submarine design industry faces many recruitment challenges in the future.

Summary

In summary, it is best to maintain a number of individuals from all identified skill categories. However, there are a few skills that take a particularly long time to develop and a few that are not used outside of the submarine design community. As these skills would take the longest to reconstitute should they be lost, assuming they could be reconstituted, they should be managed according to this risk. In a majority

of these skills, employees require a number of years of experience before reaching proficiency, and, therefore, allowing any substantial portion of the design base to dissipate will result in a number of years of unproductive design work before the workforce is fully reconstituted. Also, the loss of experienced personnel would likely jeopardize the safety and quality of the next design effort. The aging workforce will require the maintenance of an age and experience distribution of people within each skill category to ensure that a skilled design base is available for the next design effort. Ensuring that a skilled design base is available will require finding and attracting new talent to the submarine design industry and providing this new talent with submarine design work in the face of a number of recruitment challenges.

CHAPTER SIX

Suppliers

Introduction

The process of designing a submarine is a complex engineering and systems-integration task. There are a multitude of technologies that must work together in order to make the submarine a functional and safe weapon system. These technologies include systems with a direct warfighting role (e.g., communications, sonar and sensors, weapon handling systems), systems providing the mobility and power (e.g., power plant, generators, gears, hydraulic systems), and systems used to sustain the crew (e.g., galley equipment, water, air purification, berthing), all operating together in a challenging environment.

Neither EB nor NGNN possesses the capability and the technical expertise to design and manufacture the complete range of systems independently. In some cases, it would be too expensive to maintain such capabilities in-house. For example, the shipyards' suppliers are often able to leverage other customers in either the military or commercial markets, thus reducing the portion of fixed costs that any particular customer pays. The suppliers may also possess unique capabilities or technologies (through extensive research and development) that would be too expensive for the shipbuilders to develop independently. Finally, the suppliers are able to maintain technical and manufacturing specialists whom the shipbuilders would have difficulty keeping steadily employed. For example, it may be hard to justify maintaining a staff of polymer chemists who can develop formulations for hull coatings. Therefore, suppliers' technical and manufacturing expertise plays an important role in any submarine design and manufacturing effort.

In terms of value, suppliers provide roughly half of the total procurement cost for a submarine (government furnished equipment, contractor furnished equipment, and contractor furnished materiel).

Given the important role of the suppliers in the design and production of submarines, a number of questions arise as to the health of the supplier industrial base in light of a potential design gap:

- Who are the key suppliers that provided engineered components, materials, services, or equipment to past submarine design efforts?
- Will the suppliers have sufficient business to weather a design gap?
- How will the demographics of their workforce threaten design and technical skills?
- Will particular technologies become obsolete?
- Are there alternative suppliers?
- How readily can the suppliers ramp up a design effort?

In this chapter, we will attempt to answer these questions from the perspective of submarine design. That is, we will focus on suppliers who either provide engineered components for submarines or provide technical expertise to the design process. As the broader study is focused on technical skills, we do not address concerns about suppliers' ability to *manufacture* components. Our ultimate objective is to identify the number of suppliers whose *design* capabilities are at risk.

Research Approach

Because there are numerous suppliers involved in submarine design activities, it is not practical to use the same approach as we did with the shipbuilders. Furthermore, most of these firms are smaller businesses; extensive data collection and modeling activities would be overly burdensome to them. Instead, we used a simple survey to solicit information on areas of financial health, workforce demographics, design demand and ramp-up issues (e.g., hiring, training, and proficiency

issues).[1] A similar approach has been used to assess supplier issues for UK industrial base studies.[2]

We asked each of the shipbuilders to nominate suppliers that they felt have significant responsibilities as part of a submarine design. The shipbuilders identified 58 unique suppliers based on their experience with the *Virginia* class, and we sent the survey instrument to each of these suppliers. The length and scope of the survey instrument was limited to achieve a high response rate. For the same reason, we chose to limit the time required to complete the survey and asked for data that were readily available to the suppliers' management. Of the 58 suppliers identified, 38 responded to our survey; 32 of the respondents felt that they had significant activities associated with submarine design. The analysis that follows is based on the responses from those 32 suppliers.

We developed a series of metrics from the survey responses that are indicative of potential problems that would lead to a decrease in the suppliers' ability to participate in future submarine designs:

- Percentage of revenue generated by design work. During a design gap, firms with high percentages of revenue from design work will be more sensitive to gaps in design work compared with other firms that have a balance between manufacturing and design.
- Percentage of revenue from submarine business. Firms with a high percentage of work dedicated to the submarine sector will be more susceptible to changes in the submarine plan and thus have difficulty keeping workforce utilized during a design gap. Firms with a low fraction of their business in submarine work have other sources of demand that could sustain them during a gap in submarine design work.

---

1 The survey instrument sent to vendors is reproduced in Appendix C .

2 See Mark V. Arena, Hans Pung, Cynthia R. Cook, Jefferson P. Marquis, Jessie Riposo, and Gordon T. Lee, *The United Kingdom's Shipbuilding Industrial Base: The Next Fifteen Years*, Santa Monica, Calif.: RAND Corporation, MG-294-MOD, 2005; and Schank et al., *The United Kingdom's Nuclear Submarine Industrial Base: Volume 1*.

- Presence of competitors. The presence of a competitor may indicate an alternative source that the Navy and shipbuilders could use if a particular supplier left the business. The presence of competitors indicates lower risk to the government.
- Sufficient design workforce supply. Whether or not the supplier feels that there is an adequate supply of new workers is another indicator of risk. Cases where the supplier feels that it is difficult to identify and recruit new technical staff indicate that a supplier might have difficulty increasing employment at the end of a design gap.
- Demographics of the workforce. Firms with a significant portion of their design workforce nearing retirement age are at risk of losing skills during a design gap. Additionally, the loss of their more experienced personnel may mean that they will have difficulty in training a new workforce.
- Time required to ramp up a design staff. This metric is a measure of how quickly a supplier expects it can add staff to meet a new submarine design effort. A longer time indicates more difficulty in finding qualified staff and could lead to delays in meeting overall program timelines.
- Time required for a new hire to be productive. A lengthy time for new hires to become proficient indicates difficulty in growing a design staff from new hires, as well as complexity of the component to be designed. The longer the time it takes for workers to become proficient, the more complex and unique the technical issues related to the component.
- Ratio of employment to design peak. This metric measures current employment levels against the peak employment demand of a new submarine design effort. If the ratio is greater than one, the supplier already possesses a sufficient staff to meet such a peak. For ratios lower than one, the supplier does not currently have a workforce that could meet the peak demand and would have to supplement their staff.

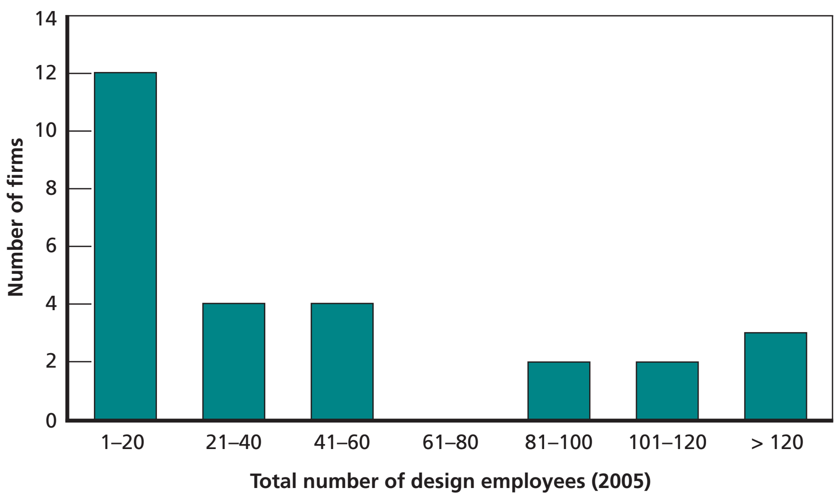
To assess relative risk, we define high-, medium-, and low-risk ranges. These ranges are based on the distribution of values for each of

the firms. For example, the possible range of the percentage of revenue from design is 0 to 100 percent. We define the low-risk range as 0 to 30 percent, the medium-risk range as 30 to 60, and the high-risk range as 60 to 100. Metrics that are binary are simply divided into high and low values. Note that not all of the metrics were reported by every firm, so in some cases, the value will be "N/R" for no response.

Survey Results

Before going into the metrics, it is helpful to characterize the size of the firms involved.[3] Figure 6.1 shows a histogram of the design staff at

Figure 6.1
Design Staff Size for Suppliers as of 2005



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3 Although some of these "firms" are actually parts of larger corporate entities, for the sake of simplicity we refer to them as firms. For the purposes of this analysis, we only use information from the business unit involved in the design work. For example, while divisions of Northrop Grumman and Lockheed Martin are suppliers, we do not include the entire corporate resources or data from these parent organizations as part of the analysis. We do not identify specific suppliers or their responses due to the sensitive nature of the data and responses.

the firms as of 2005. It is important to note that most of the firms have very small staffs compared with the shipbuilders. The modal response was between 1 and 20 employees. However, the three suppliers represented by the bar farthest to the right had design staffs consisting of over 300 people.

Percentage of Revenue from Design Work

Figure 6.2 shows the distribution for the percentage of revenue the firms receive from design work. A higher percentage of revenue from design work may indicate that a firm is very dependent on design work. Therefore, a gap in submarine design work could adversely impact the firm's financial stability. However, very few firms rely heavily on revenue from design work; the majority fall into the low-risk range. Only one firm generates a high fraction of its revenue from design and is thus designated as high risk on this dimension.

Percentage of Revenue from Submarine Work

If a supplier's revenues are highly dependent on submarine work, then a gap in submarine design work would have a greater effect on their financial viability than it would at a firm with a small portion of its revenue coming from submarine work. This is not a perfect measure of risk, as the revenue considered here comes from both design and manufacture. A firm might be sustained during a submarine design gap by production activities. In fact, the previous risk metric indicated that most of these firms' revenues come from product sales and not from design work. Nevertheless, Figure 6.3 shows that there are some suppliers that generate a large fraction of their revenues from submarine work, and these firms might be at risk.

Figure 6.3 shows a much broader distribution of revenue than does Figure 6.2. Here, there is a clear subset of the suppliers for which submarine work is a small portion of their overall revenue. The modal response is between 1 and 10 percent. There is another subpopulation where revenue is moderately influenced by submarine work (note the peak at 41 to 50 percent). Finally, there are five suppliers that generate a large fraction of their revenue from submarine work (greater than 60 percent).

Figure 6.2
Percentage Revenue from Design Work Distribution

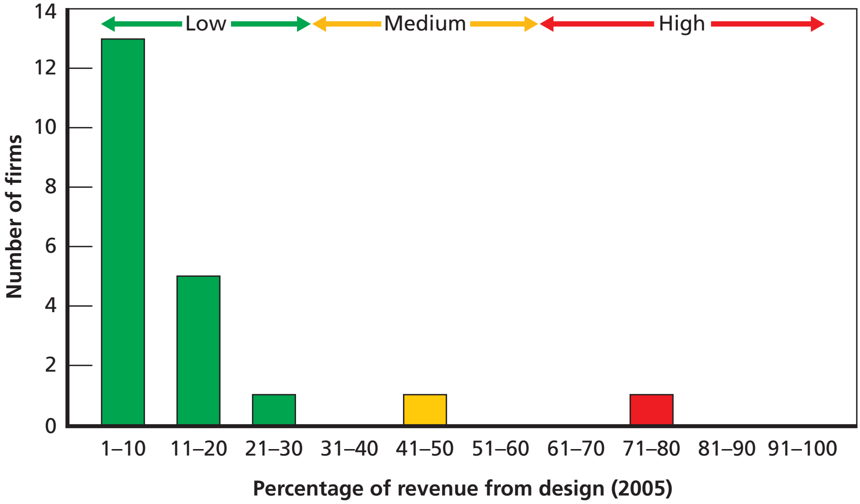

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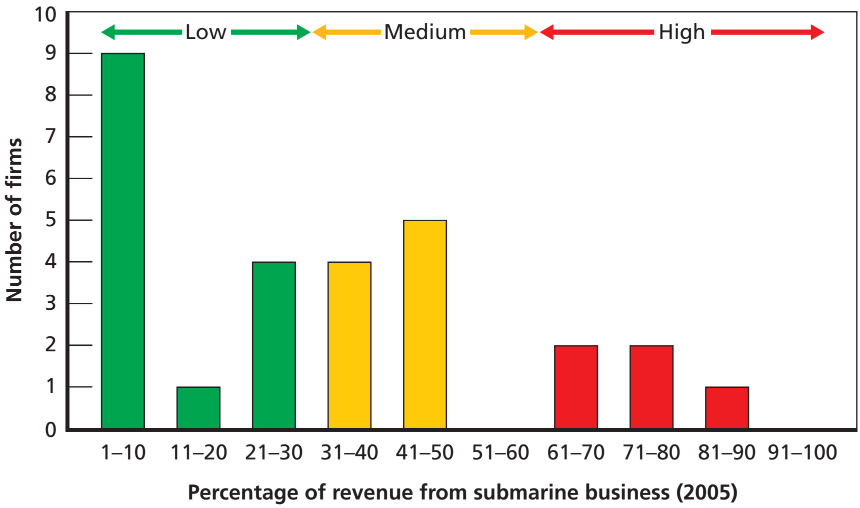
Figure 6.3
Distribution of the Percentage of Revenue from Submarine Work



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Presence of Competitors

The final metric in the business/financial category is the presence of competitors. If competitors exist in a market, buyers have alternative choices. So, if one supplier were to leave the market, there are alternative sources that the government can use. A lack of competitors means that the technology or component is likely a sole-source item, and thus entails more risk. Figure 6.4 shows the suppliers' responses as to whether or not they felt they had competitors. Almost three-quarters of the suppliers felt that they had at least one competitor in their market.

Sufficient Design Workforce Supply

We asked the suppliers whether or not they expected to have a sufficient design and technical workforce over four time horizons: 5, 10, 15, and 20 years. Obviously, the sooner that a supplier expects to have problems maintaining a sufficient workforce, the greater the risk. We view problems in the five-year window to be high risk, in the 10-year window as medium risk, and beyond that as low risk (not because that presents no potential problem, but mainly because of the uncertainty in projecting that far into the future). Figure 6.5 shows the number of suppliers that indicated that they would have a problem within the time frame. Eight suppliers felt that they would have a problem maintaining their design workforce within five years.

Demographics of the Workforce

One reflection of the risks of maintaining an adequate workforce concerns its age. The older the average age, the sooner retirements will affect the ability of the suppliers to maintain an adequate workforce. Often the individuals choosing to retire have the most experience; they may have developed unique, job-specific skills that are not found in new hires. Thus, an aging workforce is a compound problem: Not only are firms more at risk of losing people, they are at risk of losing their most experienced employees. To gauge the risk associated with this issue, we asked the firms to assess the fraction of their design workforce over the age of 45. The greater this fraction, the more risk a firm faces from retirement issues. Figure 6.6 shows the distribution of responses.

Figure 6.4
Suppliers Believing That They Have Competitors

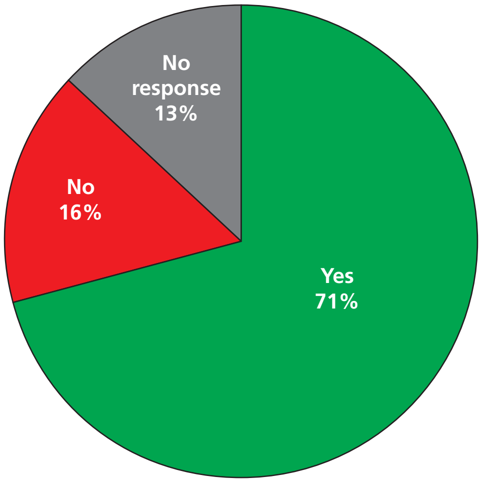

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Figure 6.5
Number of Suppliers Indicating a Problem with Maintaining a Design and Technical Workforce at Various Time Horizons

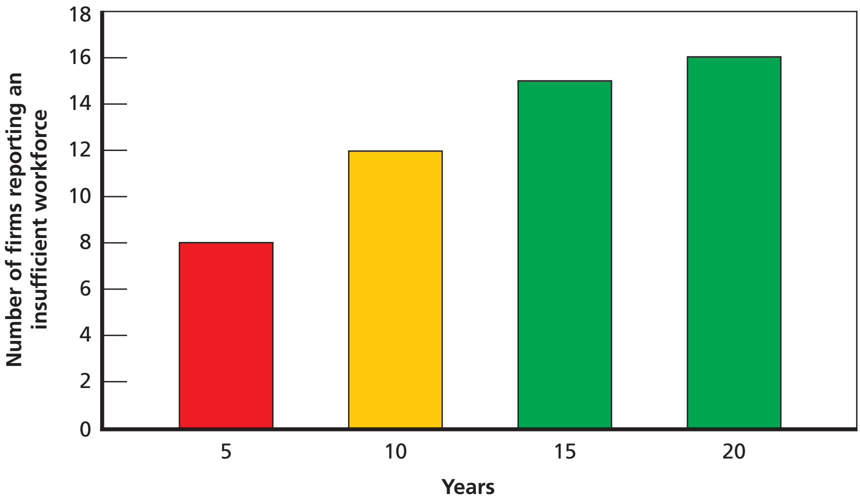

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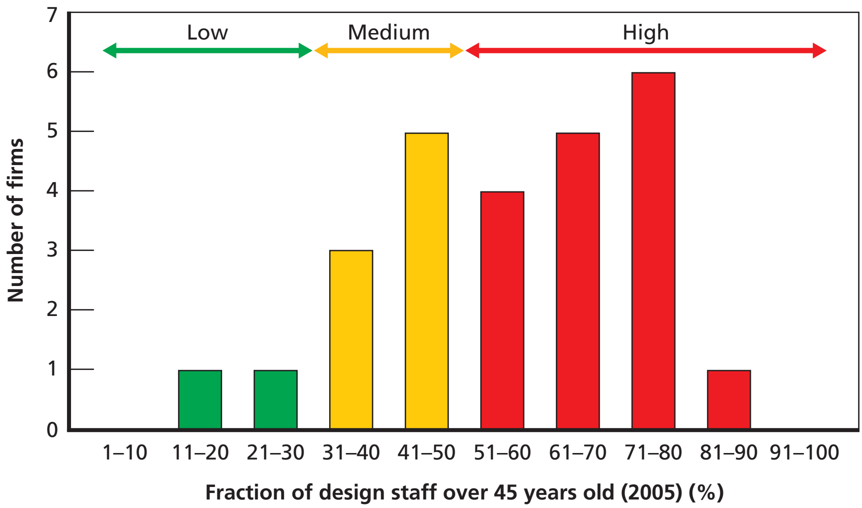
Figure 6.6
Distribution for the Fraction of the Design Staff over Age 45



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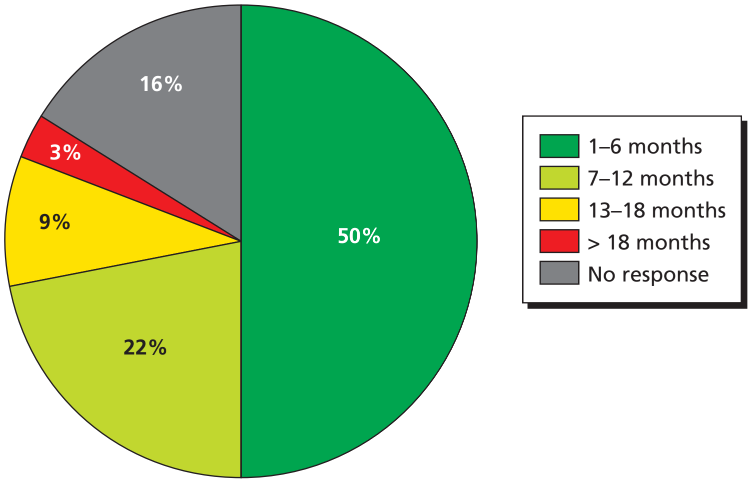
Strikingly evident from this figure is the fact that at the majority of the firms, more than 50 percent of the workforce is 45 years of age or older. Seven of the firms have an extremely high fraction of the workforce over 45 years of age (greater than 70 percent).

Time Required to Ramp Up a Design Staff

When a new design activity starts, it may be necessary for a firm to add design staff to meet the timeline. We asked each respondent to report how long it estimated such an increase would take. We divide the responses into four categories: 1 to 6 months, 7 to 12 months, 13 to 18 months, and greater than 18 months. The distribution of responses is shown in Figure 6.7. As can be seen from the figure, almost two-thirds of the suppliers think that it would take less than one year to increase their staffs to the appropriate level. Almost half the firms think that this process will take less than six months. Only 3 percent of the vendors think that it will take a significant amount of time to add staff.

Figure 6.7
Months Required to Ramp Up to Peak Staffing



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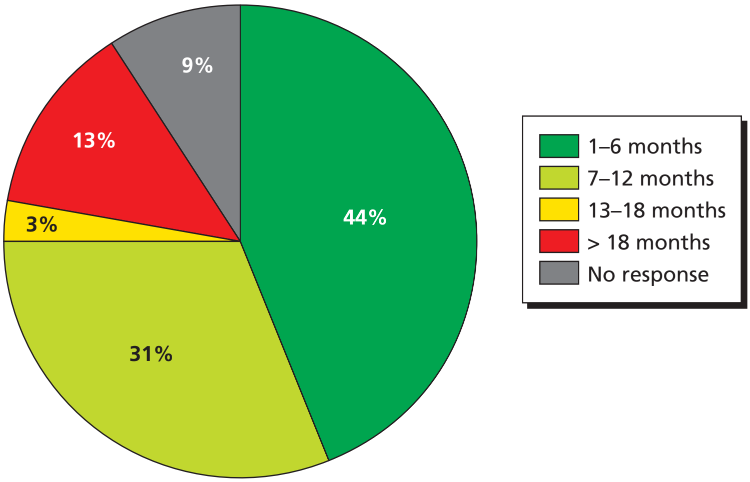
Time Required for a New Hire to Be Productive

Not only is there a risk of delay from ramping the workforce up to a desired level, there is also a lag as new hires become adapted to the job and become proficient in their roles. We asked each of the suppliers to estimate how long it would take for a new employee to become productive. These responses are categorized into the same four time ranges as the previous metric and their distribution is shown in Figure 6.8.

As was the case with the time required to ramp up the workforce, most of the suppliers feel that it takes less than one year for workers to become proficient. However, more of the firms (13 percent, or 4 companies) fall within the high-risk category—in this case, they feel that it takes more than 18 months for new employees to become productive. This longer time frame could be a reflection of the technical complexity of the firms' products or the fact that the particular skills required are not found in the general labor market.

Figure 6.8
Months Required to Become Proficient



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Ratio of Employment to Design Peak

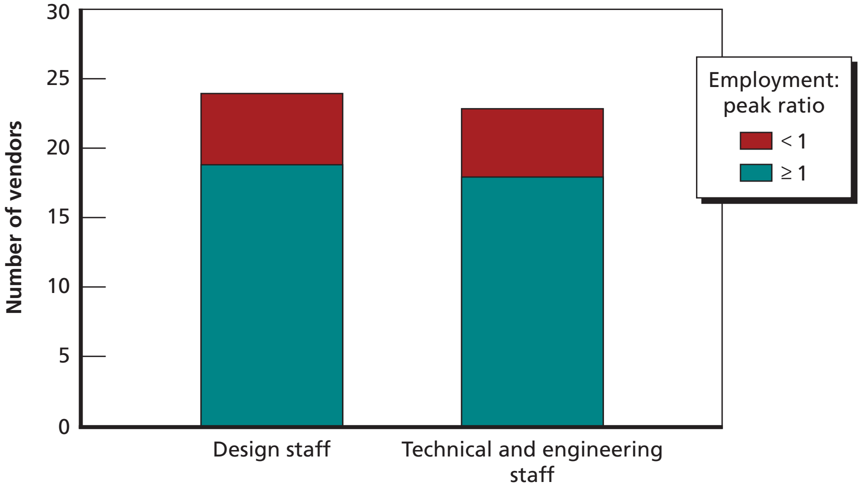
The last metric we examine is the ratio of current design employment levels to the peak needed for a new design effort. If its ratio is greater than one, the firm already possesses enough staff to meet a peak (assuming that all workers remain available). For ratios less than one, a firm would need to hire new workers in order to meet the demands of a new design effort. Figure 6.9 shows the distribution of these ratios, splitting the design staff in two ways: (1) total design staff and (2) technical and engineering workforce.

The results for both splits of the workforce are similar. Five suppliers have an employment-to-peak ratio of less than one. This low ratio indicates some risk of their having to ramp-up for a new design.

Challenges in the Submarine Industry

The surveys encouraged the suppliers to provide comments and feedback regarding their views on the potential effects of a design gap. Many suppliers voiced concerns over the lack of work during the gap and the resulting difficulty in maintaining a skilled workforce. A few

Figure 6.9
Employment-to-Peak Ratio



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vendors mentioned the possibility of pursuing other lines of business in order to retain their personnel. The following comments are typical and are indicative of the views of the vendor base:

> The largest issue that suppliers such as ourselves deal with regarding this issue is the lack of a long-term plan.
>
> These are engineers that have been with the company 3+ years and were just beginning to understand the requirements associated with Navy components.
>
> Very concerned beyond 10 years due to the aging of workforce.
>
> Through our strategy of maintaining a diversified base of business, we attempt to keep our design staff utilized.
>
> With the decline in nuclear platform design work, we have had to pursue non-propulsion business which will have the ultimate result of nuclear platforms being a declining fraction of our work.
>
> 15-20 years would result in a complete loss of the experience base to design the specialized hardware we supply to Navy.

In general, these comments show concern over the lack of a new design plan. Many vendors expressed a desire for more foresight and consistency from the Navy. Suppliers that are pursuing other work may be able to maintain their workforce; however, they may become fully dedicated in other lines of business and lose design capability for the submarine component they currently provide or may choose not to pursue future submarine work.

Synthesizing Metrics and Identifying Suppliers at Risk

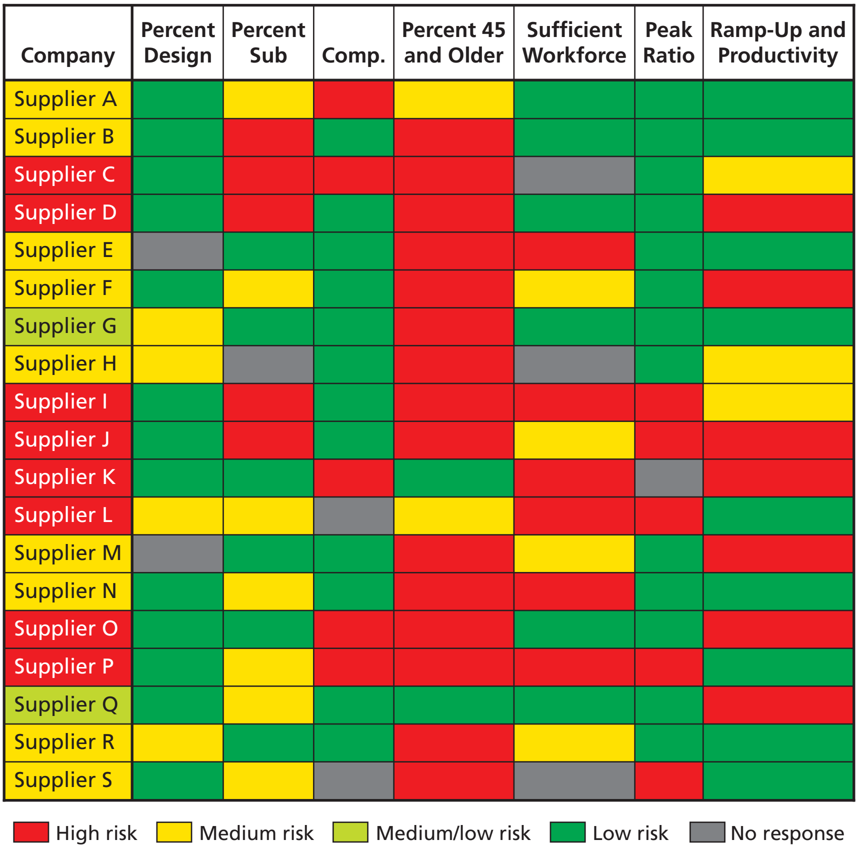
As mentioned earlier, the metrics shown above are only indicators of *risk*. It is not certain that a supplier will face difficulties with the next submarine design effort if only one of the risk metrics is in the high range. However, a supplier that has multiple metrics in the high-risk range will be more susceptible to problems. We characterized the overall risk for the vendors as shown in Table 6.1.

Figure 6.10 shows the risk assessment for those firms with greater than low risk. We masked the names of the firms so as not to disclose sensitive information about a supplier. Eight, or one-quarter, of the firms fell into the high-risk category; nine (or 28 percent) fell into the medium-risk category; and two firms (or 6 percent) fell into the medium/low–risk category. Overall, over half of the suppliers face some significant degree of risk (see Figure 6.11).

Table 6.1
Protocol for Risk Classification of Vendors

High-Risk Metrics	Medium-Risk Metrics	Vendor Classified As
3 or more	Any or none	High-risk
2	3 or more	High-risk
2	2 or fewer	Medium-risk
1	2 or more	Medium-risk
1	0 or 1	Medium/low-risk
0	2 or more	Medium/low-risk
0	0 or 1	Low-risk

Figure 6.10
Assessment of Individual Supplier Risk



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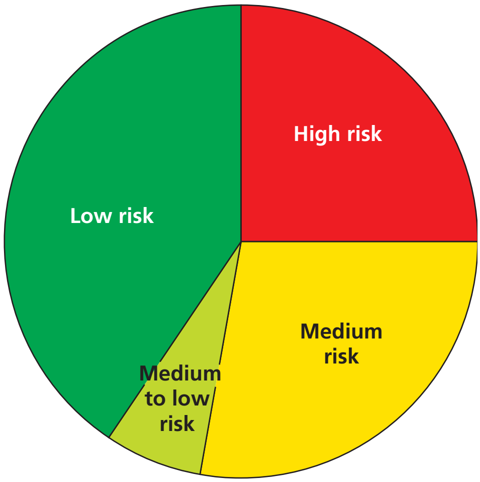
Options to Address Vendor Risk

Listed below are options that might help mitigate supplier issues. Unlike the situation for the shipbuilders, there are a variety of options that might be used to mitigate a design gap. The applicability of each option will in part depend on the circumstances of a particular supplier. Three of the options forgo the need for a new component design

Figure 6.11
Distribution of Vendors Across Risk Categories



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from a specific vendor, through either substitution or reuse. The other two options attempt to help vendors sustain and build a design staff during the gap.

- *Seek a competitive solution.* If the component or technology is not unique to a specific supplier, an alternative source could be sought. This option is feasible only if competitors exist and are able to maintain their design resources during the current design gap. There are potential downsides to this approach. One is that the component/technology will need to be re-qualified, which would add additional cost. Another is that the replacement firm may not be as familiar with specific submarine standards, which would entail learning and modification costs.
- *Replace technology.* The next submarine class may not need a specific component currently provided by an existing vendor. For example, it is possible that a newer technology may replace an existing one. Many of the same drawbacks of competitive solutions apply here in terms of additional development and qualification costs. In some cases, the replacement could be a step back-

ward in using an older technology to fill a need (at the expense of capability).

- *Reuse the current component design.* A component may not need to be redesigned for the next submarine class if it meets the required performance attributes. As long as steady production is maintained, the supplier will likely stay in business producing the item. However, the downside of this option is that it moves the design resource problem into the future, stretching the gap in demand for the design of the component.
- *Stretch the next new submarine design period.* As with the shipbuilders, it might be possible to extend component design over a longer period of time to reduce the peak in the design workload. However, this option may not work for many of the suppliers, as their design peak workloads are relatively small. In essence, it may not be possible to shrink the peak because of the diverse skills and people required for a design effort (i.e., a person cannot be cut in two). While stretching the design might move work earlier than otherwise planned, this strategy might create a gap after the design is complete that would also need to be mitigated. We felt that this option would be appropriate only for suppliers with peak design demands greater than 25 people and that are currently staffed less than the peak of demand.
- *Use spiral development for the* Virginia *class.* In an attempt to maintain design staffs, the Navy could initiate modernization design work with an at-risk supplier. This strategy will likely best work for non-HM&E items, such as combat or communication system components. It could be too expensive to implement significant layout or structural changes. Such an approach might result in increased manufacturing costs. Implementing this option would require research, development, testing, and evaluation funds.

Table 6.2 displays the possible options for the previously identified vendors, as we judge them. At least one option exists for each supplier. Stretching the design effort, the most promising option for the shipbuilders, helps only a handful of the suppliers and will likely not be sufficient to protect the supplier base. The design stretch strategy

Table 6.2
Potential Supplier Mitigation Options

Company	Seek Competitor	Replace Technology	Reuse Technology	Stretch Design	Spiral Development
Supplier A			√		√
Supplier B	√	√	√		
Supplier C			√	?	
Supplier D	√		√	√	
Supplier E	√	√	√		
Supplier F	√	√	?	√	
Supplier G	√	√	√		
Supplier H	√	√	√		√
Supplier I	√		?	√	
Supplier J			?	√	√
Supplier K		√	√		
Supplier L	√	√	√		
Supplier M	√	√	√	√	
Supplier N	√	√	√		
Supplier O			√		
Supplier P			√		
Supplier Q	√	√	√	√	
Supplier R	√	√	√	√	
Supplier S	?	√	√		

will need to be supplemented with some combination of reuse, replacement, and spiral development to minimize risk among the vendors. Reuse is the most broadly applicable option. The choice of a particular mitigation strategy largely depends on whether a new capability will be required in the future and whether replacement technology is planned. Such issues are beyond the scope of our analysis. The Navy and the shipbuilders will need to assess how critical a technology is to the over-

all system solution and whether enhanced capability will be necessary for the next submarine design.

Observations

Based on our survey of suppliers that have some role in submarine design, we observe that roughly half the vendors will have trouble maintaining design capabilities during the design gap. Several of them will be at-risk in the next five years and many in the next decade. As an important first step to mitigating this risk, the Navy and shipbuilders should identify critical technologies to protect. But, vendor mitigation strategies will have to be vendor-specific, as one fix will not fit all.

CHAPTER SEVEN

The Navy's Roles and Responsibilities in Submarine Design

The Navy ultimately retains the responsibility of ensuring that a submarine design is safe, effective, and affordable. This responsibility is independent of the entity that actually designs the submarine, whether the design is an internal Navy effort or, as is the practice today, an effort by a private corporation under contract to the Navy. This responsibility has not changed, despite significant changes in the division of labor between the Navy and private industry and in design tools and practices.

In carrying out its responsibility, the Navy fulfills three roles: providing technical infrastructure and expertise, developing and designing components, and supporting science and technology. This chapter first describes the Navy's responsibilities in each of these roles, including the various programmatic and technical functions. It concludes with a discussion of the current distribution of design resources within the Navy's institutional structure. This background information lays the foundation for the examination of the effect of a design gap on the Navy's technical community and the discussion of methods to best mitigate this effect, both of which are presented in Chapter Eight.

Defining the Navy's Submarine-Related Roles

Technical Infrastructure and Expertise

The Navy serves as the final approval authority for submarine design, responsible for the engineering certification of the completed design product and all of its subsystems. This authority includes not only the technical acceptability of the design from a functional and safety standpoint, but also the ability of the design to meet programmatic requirements. Additionally, the Navy is responsible for ensuring that the finished product is fully tested and meets its warfighting requirements. This technical infrastructure and expertise role can be subdivided into three functions: acting as a smart buyer, providing technical authority, and conducting testing and evaluation.

Smart Buyer. As the end user of the submarine design, the Navy must ensure that the design efficiently meets its program requirements. Historically, this has been accomplished by the Navy in either of two ways: being heavily involved in the design process, effectively designing the submarine itself, or undertaking periodic detailed and painstaking reviews of the physical mock-ups and requiring significant redesign effort when changes were needed. Significant changes following the detailed design phase often result in cost overruns and schedule slippage. Beginning with the *Virginia*-class program, an IPPD initiative was undertaken to provide for a collaborative design approach.[1] Under IPPD, the Navy was integrated into the design team under the auspices of the program office, affording the opportunity for the Navy to provide its feedback as the design evolved. In so doing, the Navy was able to ensure that program requirements were being met without the time- consuming and disruptive periodic mock-up and design reviews that marked previous design efforts.

Integral to the Navy's role as a smart buyer and its involvement in the IPPD process is the engineering and technical support provided outside of the program office. The NAVSEA headquarters and the warfare centers provide a rich pool of technical expertise that is available to answer technical questions and resolve problems that fall outside of

[1] Winner, *Integrated Product/Process Development*, p. 2.

the scope of the IPPD. This internal Navy technical community is able to participate in the design process as an active member of the design team and effectively fulfill its responsibility of ensuring that program requirements are being met.

Technical Authority. Ensuring a submarine design is safe requires technical adjudication as to whether or not design elements adhere to established technical standards and policy. This technical adjudication must look not only at individual elements of the design but also at the interaction of individual elements as they aggregate to larger systems and structures. The technical adjudication must be independent of the design team to ensure that technical standards are not sacrificed to meet project schedule or cost-savings demands. The Navy provides this independent and objective evaluation of the submarine design and has the final say as to whether or not the submarine and its subsystems adhere to established technical standards and policy.

The Navy administers this technical authority by virtue of its technical warrant holder program. Technical warrant holders are chosen based on their expertise in a given area and derive their authority from the Secretary of the Navy via the Commander of NAVSEA. Each technical warrant holder is responsible for the stewardship of his or her technical support structure to ensure that it maintains the necessary competence. The technical warrant holder certifies that the design is safe, technically feasible, and affordable within his or her area of expertise. This certification process, which operates under a memorandum of understanding between NAVSEA and the program executive office (PEO), ensures that engineering reviews are independent of program and budgetary pressures. Currently there are 172 technical warrants divided into six categories. Ship design managers (SDMs) manage systems-engineering efforts for their assigned platforms. Chief systems engineers (CSEs) assist SDMs in the systems-engineering integration of complex warfare systems into platforms. Cost engineering managers (CEMs) provide independent cost engineering and estimating in support of Navy programs. Technical area experts (TAEs) provide system-level expertise to the SDMs and CSEs; an example of a TAE is the technical warrant holder for ship habitability systems. Technical process owners (TPOs) are responsible for the definition and doc-

umentation for technical processes. For example, TPOs are assigned for ship certification processes. Depot chief engineers (CHENGs) lead and focus the technical efforts of the Navy from the waterfront and depots. Under each technical warrant holder is a pyramid of support that includes engineering managers and lead engineers.[2] A complete list of technical warrant holders is provided in Appendix D.

Testing and Evaluation. Upon the completion of the construction of a submarine, a rigorous testing program is required to ensure that the boat meets its design performance requirements. This testing program also provides important feedback to the design process, allowing changes to be made for subsequent ships built to the same design. Like other aspects of submarine design, testing and evaluation is a collaborative effort of the Navy with the building shipyard and the design yard. However, because of the unique infrastructure required to test submarines, the Navy takes the lead role.

Component Design and Development

The Navy retains responsibility for the design and development of certain submarine components, including components that are critical to submarine safety, components for which the Navy does not provide sufficient demand to sustain an industrial base, components that are associated with the nuclear propulsion plant, and components that are required for the integration and interoperability of the command, control, communications, computer, and intelligence (C4I) and combat-control systems. Additionally, the Navy maintains testing facilities that are required in the submarine design process but which are not commercially viable for private industry to maintain.

For components that are critical to submarine safety and/or are not commercially viable, the Navy retains design control and manages component construction, delivering the component to the shipbuilder as government furnished equipment. One example of a critical safety component is the algorithms used for automated ship control systems; acoustic hull coatings and sound-damping material are examples of

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[2] U.S. Naval Sea Systems Command, *Virtual SYSCOM Engineering and Technical Authority Policy*, VS-JI-22, January 3, 2005.

components for which there is not enough demand to sustain a commercial base. The submarine propulsor is an example of a component that is both critical to submarine safety and more cost effective to design and develop under Navy management.[3]

The integration and interoperability of C4I and combat systems remains under Navy management largely to facilitate development outside of submarine hull acquisition programs. In so doing, the Navy achieves a rapid technology refresh rate and the ability to modernize the in-service submarine fleet. Like other aspects of submarine design, there is a significant amount of collaboration between the Navy and private industry to ensure that existing C4I and combat systems will work with new submarine designs.

The ability to conduct testing to validate design models and calculations is integral to the design process. Hydrodynamic performance evaluation, pressure-hull and large-scale equipment shock testing, and other testing require large facilities and highly trained operators and engineers. Much of this infrastructure exists today at Navy facilities as a result of the Navy's previous practice of internally designing ships and submarines. As more design efforts shift to private industry, it is not cost effective to duplicate this large testing infrastructure. Consequently, the Navy retains management and operation of these facilities under direct reimbursement from private industry when the Navy must support private industry design efforts.[4]

Science and Technology

The Navy is responsible for maintaining the technology base that supports submarine design. Navy- and government-funded research is almost exclusively conducted by government institutions, including the Navy's warfare centers, private industry, and academic institutions. In order to effectively organize its submarine-related science and tech-

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[3] *Propulsors* have replaced traditional propellers in U.S. submarines as the means by which power is transferred from the main engines to move the ship through the water.

[4] These facilities are maintained within the naval warfare centers, which, as working capital organizations, require reimbursement from customers, both private and government, to maintain facility capitalization.

nology (S&T) activities, the Navy established the Submarine Technology (SUBTECH) organization in 1997. SUBTECH develops a consensus on submarine S&T priorities and provides recommendations to the resource sponsors within the Office of the Chief of Naval Operations.[5] SUBTECH is organized around four integrated product teams (IPTs): ForceNet, Sea Strike, Sea Shield, and Platform Technologies (Sea Basing). The ForceNet IPT focuses on submarine communication issues, including communication at speed and depth, onboard and off board sensors, and unmanned undersea vehicle (UUV) systems. The Sea Strike IPT covers the full range of weapon systems carried by submarines. The Sea Shield IPT deals with self-defense capabilities, large-area search and cueing, and renewable energy sources for UUVs. The Platform Technologies IPT is the most applicable to *new* submarine design. Platform Technologies looks at issues related to alternative submarine designs, distributed propulsion technologies, and electric ship technologies.

The Navy's S&T efforts, as carried out by SUBTECH, tend to focus on the needs of the future Navy. Consequently, the S&T funding is directed away from the warfare centers. The warfare centers primarily support the deployed Navy and the next Navy (platforms already designed and platforms being designed, respectively). Figure 7.1 shows the level of submarine-related S&T funding at the warfare centers since the end of the Cold War. At both the Naval Undersea Warfare Center (NUWC) and NSWC, S&T funding has declined by 50 percent since its peak following the Cold War.

Program Authority Versus Technical Authority

One of the strengths of the Navy's acquisition process is its separation of the responsibility for managing acquisition programs from the technical approval process. Program managers responsible to the Assistant Secretary of the Navy (Research, Development, and Acquisition) are

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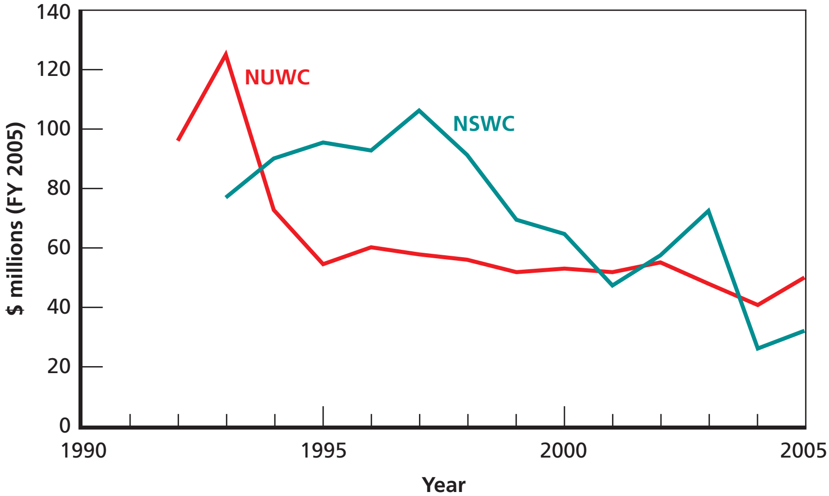
[5] Steve Weinstein, "Submarine Technology (SUBTECH) Overview," briefing to the ONR Naval-Industry Research and Development Partnership Conference, August 2004.

Figure 7.1
Submarine-Related S&T Funding at the Naval Warfare Centers



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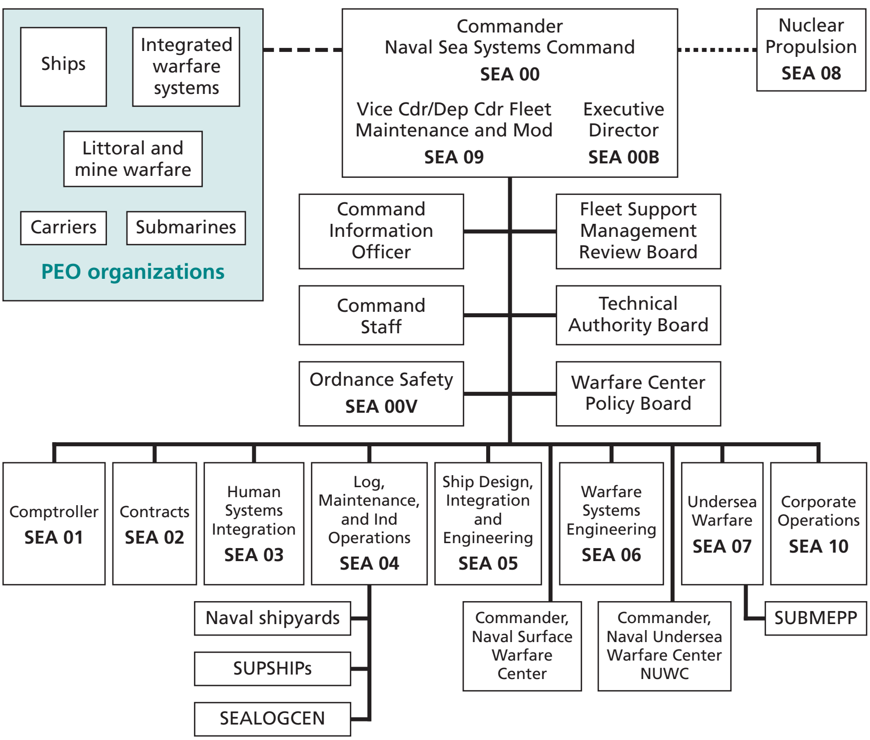
charged with managing the performance of their particular programs in both cost and schedule terms. The Navy's technical establishment, on the other hand, is responsible only for the technical acceptability of the product design. The technical establishment falls under the direction of the Commander of NAVSEA to ensure the independence of technical decisions. While program management and the technical approval process are organizationally independent of each other, a close working relationship is maintained by seconding NAVSEA technical personnel to the program manager's staff. This practice ensures program decisions are firmly grounded in technical realities.

Navy Design Resources

The Navy's design resources are physically and organizationally dispersed between NAVSEA headquarters and its naval warfare centers. NAVSEA engineers oversee design, construction, and support of the Navy's fleet of ships, submarines, and combat systems. NAVSEA consists of a headquarters organization and a variety of technical organiza-

tions throughout the country, including the naval warfare centers and public naval shipyards (see Figure 7.2). NSWC and NUWC report directly to the Commander of NAVSEA but are treated as separate entities in this report, while the NAVSEA headquarters organization (SEA 01 through SEA 10 in Figure 7.2) is here referred to as NAVSEA. Within NAVSEA, the Ship Design, Integration and Engineering Directorate (SEA 05) and the Undersea Warfare Directorate (SEA 07) make significant contributions to the design of new submarines. SEA 05 (see Figure 7.3) ensures ships and submarines are safe, operationally superior, and affordable. It evaluates and designs new ship concepts and oversees the in-service engineering of the fleet. SEA 07 develops

Figure 7.2
NAVSEA Corporate Structure



SOURCE: www.navsea.navy.mil.
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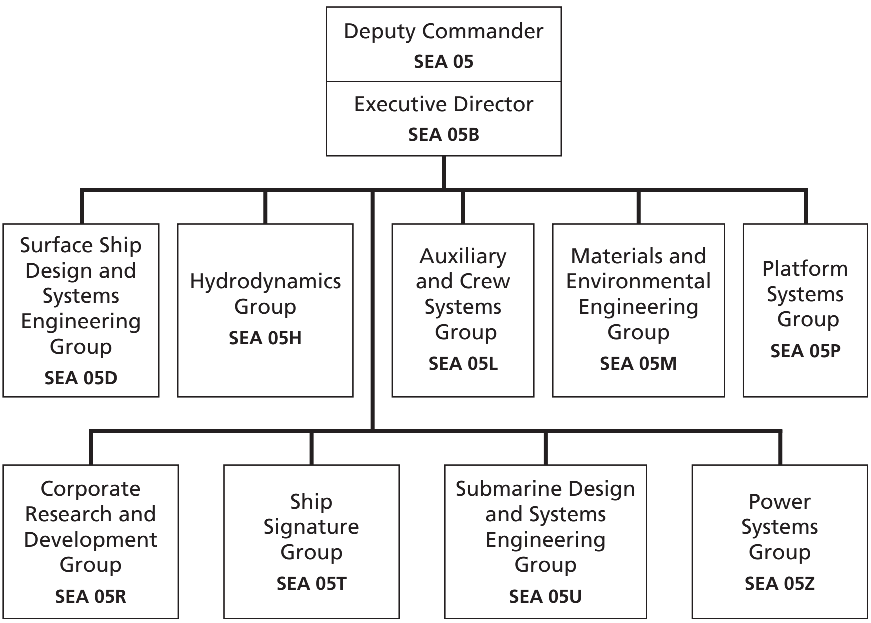
submarine systems, autonomous underwater systems, and offensive and defensive weapon systems.[6]

NSWC and NUWC are Navy working capital organizations, and as such are required to move personnel and resources in response to program funding. The funding for the warfare centers is based on contracts negotiated with resource sponsors within the PEO community, NAVSEA, and other Navy or military customers. As the undersea warfare center of excellence, NUWC focuses on combat and sonar systems, UUVs, communications, and sensors. The bulk of the new submarine design activity within NUWC occurs at its Newport Division. NSWC Carderock Division is the Navy's center of excellence for sur-

Figure 7.3
SEA 05 Ship Design Integration and Engineering



SOURCE: NAVSEAINST 5400.1F.
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6 NAVSEA has recently reorganized its corporate structure; the text and figures in this work reflect the NAVSEA organization at the time our research was conducted.

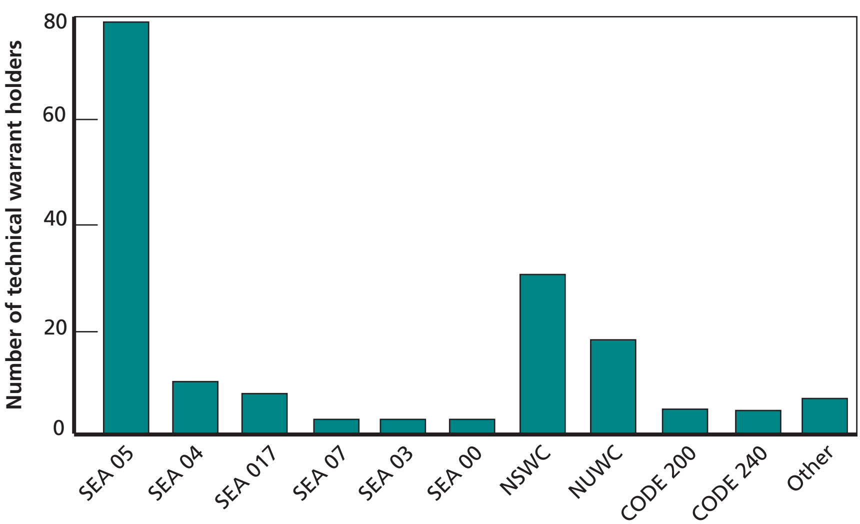
face and undersea HM&E systems and propulsors. Among the NSWC divisions, the Carderock Division performs the bulk of the submarine design efforts.

NAVSEA relies on two separate mechanisms to manage these large technical organizations. These dual management chains as well as the military commanders at the warfare centers ensure the technical base is maintained in a cost-effective manner.

The first organizational mechanism consists of the technical warrant holders, who are responsible for maintaining engineering and scientific quality within their warrant area. As shown in Figure 7.4, many of the technical warrant holders reside within SEA 05. However, the bulk of technical support within individual warrants is found within the warfare centers. The technical warrant holder program allows NAVSEA to monitor the health of engineering resources that are spread out among the warfare centers.

The second organizational mechanism, product area directors (PADs), provides functional management across the warfare centers (see Figure 7.5). They maintain resources and technical capacity and

Figure 7.4
Many Technical Warrant Holders Reside at NAVSEA 05



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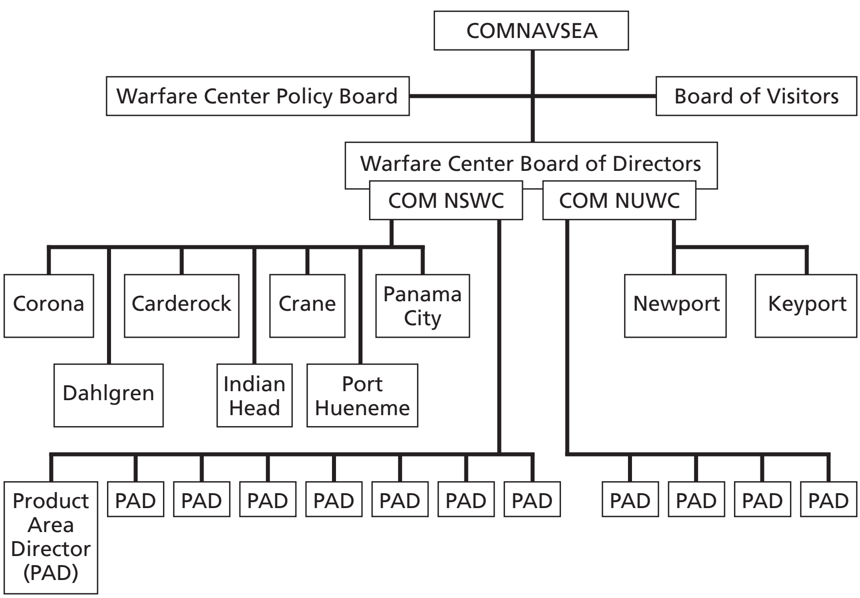
serve as a clearinghouse for the allocation of work within their respective areas. Currently, there are PADs for

- force-level warfare systems
- ships and ship systems
- surface ship combat systems
- littoral warfare systems
- Navy strategic weapon systems
- ordnance
- undersea warfare (USW) command and control systems
- USW weapon and vehicle systems
- USW analysis and assessment
- USW fleet material readiness
- homeland and force protection
- surface warfare logistics and force protection.

Figure 7.5
Integrated Warfare Centers Organizational Structure



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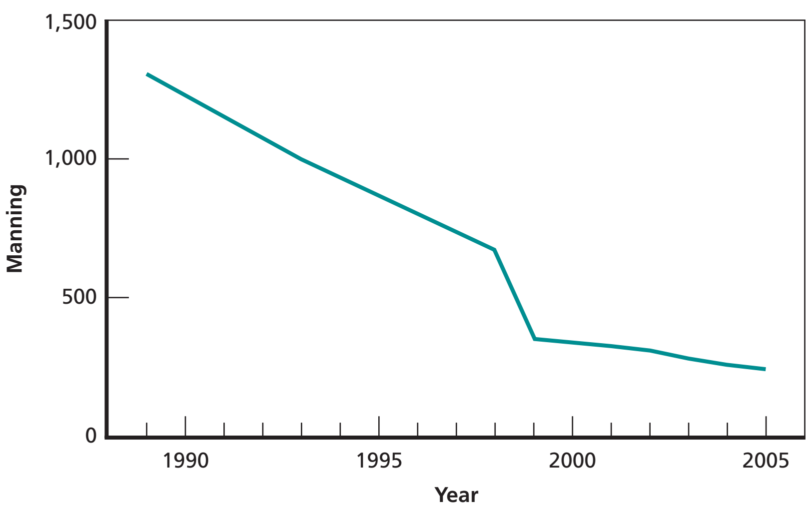
As discussed previously, the means by which the Navy has accomplished its submarine design role have evolved. One of the principal drivers of this evolution has been the Navy's desire to cut the size of its workforce to reduce cost. Consequently, the Navy's personnel design resources have undergone significant changes as the workforce has been reduced and restructured. Today, the majority of Navy personnel involved with the technical aspects of submarine design reside in the warfare centers, while the management and senior supervisory personnel mostly reside in the NAVSEA headquarters organization and within the program offices themselves.

Historically, Navy design personnel were resident in SEA 05. SEA 05 conducted a significant amount of submarine design work, as demonstrated in the development of the *Los Angeles* class and prior submarine classes. Due to budgetary pressure, SEA 05's staffing levels have fallen to 20 percent of its Cold War level (see Figure 7.6). In conjunction with this personnel reduction, many of the design functions previously performed within SEA 05 were shifted to the warfare centers, with a consequent transfer of personnel.

Figure 7.6
SEA 05 Manning Levels



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Despite the influx of personnel from SEA 05, overall manning levels at the warfare centers have also declined. This has occurred because the warfare centers have also been under pressure to decrease their manning levels as the Navy attempts to reduce its overall personnel costs. NSWC's Carderock Division has undergone a 15 percent reduction from its manning peak. Likewise, NUWC's Newport Division has undergone a 20 percent manning reduction from its peak. These reductions, particularly within the science and engineering communities, have been small relative to those at NAVSEA headquarters.

As a result of these personnel reductions and shifts, most of the Navy's technical workforce is now resident within the warfare centers. This is noteworthy, because the personnel costs at the warfare centers are expenses reimbursable by the program offices under the Navy working capital funds construct. In contrast, personnel assigned to NAVSEA are mission funded, essentially billable to Navy overhead accounts and not reimbursed by the program offices. Under Navy working capital funding, activities must be funding-neutral, billing their customers to meet their costs. As a result, the program offices now have to pay for the Navy's technical assistance, which has the effect of appearing to increase development costs due to using working capital instead of mission-funded resources. The shifting of design work from the Navy to the contractors has a similar effect. Work previously performed by engineers that was paid for by overhead accounts is now performed by the contractor, which appears to increase development costs.

Summary

In this chapter, we describe the Navy's roles in submarine design, how the Navy's design process has evolved, and the current distribution of design resources within the Navy organization. The Navy is responsible for a safe, effective, and affordable submarine design. To that end, the Navy has three critical roles:

- technical infrastructure and expertise, which includes the Navy's certification authority for the final design product from both a

functional and safety standpoint, and the design's adherence to programmatic requirements
- component design and development for components that are critical to submarine safety, associated with the nuclear propulsion plant, critical to the integration and interoperability of the C4I and combat control systems, or not commercially viable for private industry
- S&T support to maintain the technology base that supports submarine design.

While the Navy's roles in submarine design remain important, the method by which the Navy goes about executing its roles has evolved. A process under which the Navy was the principal design agent has been replaced by one in which the Navy collaborates with industry. Simultaneously, the Navy has shifted from a headquarters-centric design resource pool to a more dispersed organization, with most of the design resources residing in the warfare centers. Consequently, the Navy has adopted several programs to manage this dispersed organization to ensure the necessary skills can be maintained in a cost-effective manner.

CHAPTER EIGHT

Effect of a Design Gap on the Navy's Technical Community

The U.S. Navy has an extensive technical infrastructure designed to assist in the acquisition and in-service support of nuclear submarines. This chapter examines the effect a prolonged design and engineering gap will have on that technical infrastructure. The design gap has implications for manning within the Navy's engineering community and for funding levels required to provide technical work that is challenging enough to maintain skill levels. The effects vary across the organizational structure, and we use that structure to frame our analysis drawing on the discussions of NAVSEA and the naval warfare centers in Chapter Seven.

We have already discussed the potential effects of a design gap on the shipbuilders and vendors. The workload gap's effects on a government agency are similar in many ways to its effects on a private firm, with some notable exceptions. Typically, government organizations have more constraints on their ability to hire and fire workers than does a private firm. Additionally, government agencies, particularly within the Department of Defense (DoD), are not involved with production but with specialized technical tasks that may require significant on-the-job training and specific education backgrounds. These parameters can make rebuilding the workforce within the government difficult and expensive.

Effects of the Design Gap on NAVSEA

The effects of a gap in new submarine design should be measured by its impact on an organization's technical infrastructure, such as funding levels for personnel and facilities. Then, the impact of a design gap on the quality of the technical work available to the engineers should be assessed. In other words, will the work required by the Navy during the design gap be of sufficient quality and complexity to maintain those skills required to design a new submarine? NAVSEA is likely to maintain its technical infrastructure during a gap because of its status as a mission-funded activity and its ongoing fleet support activities. The dominant engineering organizations within NAVSEA, SEA 05 and SEA 07, are heavily involved in the technical stewardship of the in-service fleet and the on-going construction of the *Virginia*-class submarines. As a result, the manning levels within those organizations will not be directly affected by a design gap.

Assuming that manning levels will remain relatively stable during the design gap, the quality of work available to the engineering community must be addressed. The lack of submarine design programs will have several deleterious effects on the NAVSEA technical community. According to interviews with Navy technical managers, the technical refresh of undersea warfare systems such as sonar, combat, and communications should maintain the technical skills of SEA 07. However, in-service submarine support will maintain most, but not all, skill sets in SEA 05.

The Submarine and Submersible Design and Systems Engineering Group, SEA 05U, maintains the ship design manager technical warrants for all classes of submarines. Ship design managers manage the integration efforts for their platforms. The lack of ongoing design programs degrades the ability of SEA 05U to properly develop ship design managers. In particular, designing a new submarine allows the engineers to exercise their whole-ship-integration skills. The impending design gap will erode those integration skills and retard the development of senior managers capable of providing leadership during subsequent design efforts.

The effect of the gap on whole-ship-integration skills and on senior-management development will heavily depend on its length. A short gap will have minimal impacts while a longer gap will have increasingly negative impacts. In addition to whole ship integration, SEA 05 is heavily involved in writing detailed shipbuilding technical specifications that are required for the shipyards to design the submarine the Navy desires. SEA 05's proficiency in creating detailed technical specifications will decrease in the absence of a design program. Overall, NAVSEA is likely to maintain the technical infrastructure during a design gap, but its ability to accomplish whole ship integration tasks will erode.

Effects of the Design Gap on the Naval Warfare Centers

The naval warfare centers comprise the bulk of NAVSEA's and the Navy's technical resources and facilities related to the design of new submarines. The warfare centers provide the engineering talent and the facilities to perform most of the Navy's technical work. When assessing the effects of a design gap, it is important to note that NUWC and NSWC are working capital organizations. As a result, personnel will shift away from submarine work in the absence of sufficient funding, and underutilized facilities will shut down or must be supported by overhead accounts. Shutting down facilities is often the most economical course of action, but often is unpalatable to the Navy leadership. This results in the warfare centers relying on overhead to make up for any funding shortfalls. All increases to the overhead rate will have a negative impact on all Navy programs interacting with the warfare centers, which are required to maintain their reimbursement rate to remain cash-flow neutral.

Variation of Effect with Technical Area

The effects of a design gap on the naval warfare centers depend on the technical areas involved. Those areas focused on HM&E systems are very sensitive to a gap in new submarine design, while non-HM&E areas are relatively insensitive. In-service modernization programs

comprise the bulk of NUWC's program funding and provide a healthy technical basis for new submarine designs.

Because HM&E engineering is not a salient activity at NUWC, those facilities at NUWC required for new design programs are generally well supported by in-service modernization programs. Only 5 percent of NUWC's budget from FY 1999 to FY 2010 is estimated to originate from new submarine design programs.[1] The design gap will affect NUWC's ability to support future submarine design efforts in two areas. First, the skills required to integrate NUWC's various combat and sonar systems into a new hull design are in jeopardy to the extent that they are not exercised in modernization programs. Secondly, in-service modernization programs tend to focus on updating systems and components within the submarine hull. This leaves wet-sensor technology development and integration skills particularly vulnerable.

The Navy's HM&E technical resources at NSWC's Carderock Division will be strongly affected by any design and engineering gap. Submarine acquisition programs provided nearly 40 percent of the FY 2005 funding for submarine technical work at the Carderock Division. This included funding to support the design and construction of the *Virginia* class, the SSGN conversion, and the MMP for SSN 23. The Carderock Division is heavily involved in any Navy submarine design effort, from the initial concept design and planning documentation through testing and evaluation during sea trials. Figure 8.1 indicates the profile of funding to the Carderock Division from the *Virginia*-class design program over that program's life. The funding profile from the *Virginia*-class program is essentially constant because of the range of technical activities of the Carderock Division, which was heavily involved in the initial design, resulting in significant funding early in the program, and is also heavily involved in the testing and evaluation phase, which accounts for the high levels of funding at the end of the program. As the testing program for the *Virginia* class is completed, the funding will decrease substantially over the next year or so.

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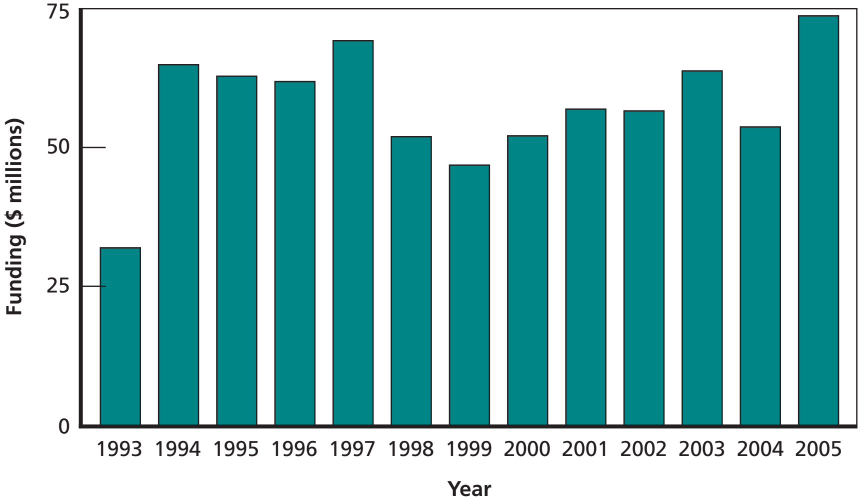
1 Pierre Corriveau, Undersea Warfare Command and Control Systems Product Area Director, "Undersea Warfare Command and Control, Weapons and Vehicles, and Analysis and Assessment Product Areas," briefing, January 26, 2006.

Figure 8.1
***Virginia*-Class Program Office Funding to NSWC, Carderock Division, over the Design Program Lifetime**



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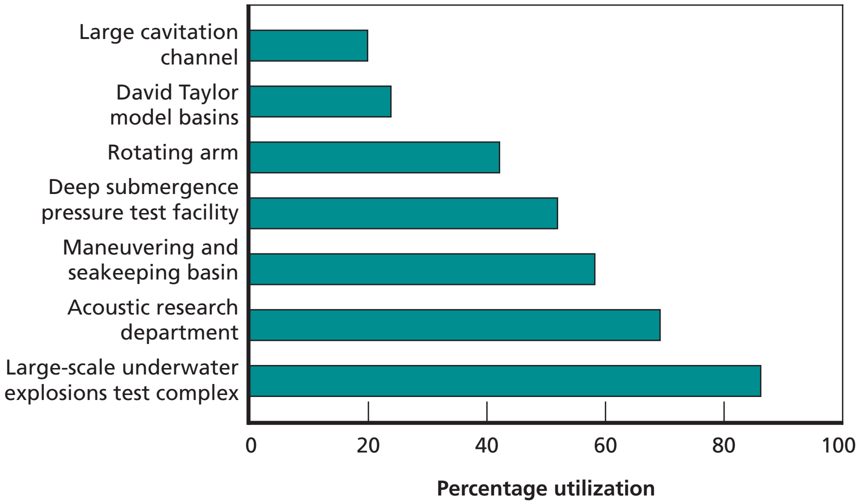
The Carderock Division has a large, on-going effort in component design for which it maintains an in-house design capability. This includes the design of components that industry is unable or unwilling to produce, such as propulsor design and system integration, as well as work on hull coatings and damping materials. These technical skills and design capabilities are not replicated within the industrial base. In addition to its workforce, the Carderock Division maintains several facilities that are necessary for a successful submarine design but that cannot be economically supported by industry (see Figure 8.2). In a 2005 assessment, NSWC indicated that these facilities are already showing signs of under-utilization. In the absence of sufficient program support, these facilities will have to be laid up or placed on overhead accounts at NSWC.

In-service submarine support, technical assistance to the *Virginia*-class production program, and ongoing science and technology programs will not support the skills required for a full submarine design effort. Table 8.1 indicates the manning levels required at the Carderock Division (as determined and provided to us by sub-

Figure 8.2
Prominent Design Facility Utilization at NSWC's Carderock Division



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ject-matter experts at Carderock) to support a full submarine design, based on the recent experience with the *Virginia* class and the manning level required to sustain a minimum level of knowledge. Maintaining a minimum level of knowledge will allow the Carderock Division to rebuild its workforce efficiently to support subsequent submarine design efforts. Carderock has received an average of $113 million per year, or approximately $323 thousand per employee per year, in support of its submarine technology programs since the end of the Cold War. Supporting the core technical group at $323 thousand per employee per year requires a funding level of $55 million per year. In-service support and technology development programs have averaged $23 million per year in funding. This leaves the Carderock Division facing a $30 million to $35 million per year gap in the funding required to support its core technical group of personnel and facilities. As a working capital organization, Carderock's engineers will follow program funding and transfer to non-submarine areas within the warfare center as submarine program funding declines.

Table 8.1
Manning Levels to Sustain Design Capability and to Support a Full Submarine Design Effort

	Number of Personnel Required to	
Technical Capability	**Sustain Design Capability**	**Support Full Submarine Design**
Ship design and integration	4	14
Ship acquisition engineering	1	3
Hull forms, propulsors, and fluid mechanics	48	73
Mechanical power and propulsion systems	4	14
Electrical power and propulsion systems	4	10
Auxiliary machinery	7	22
Undersea vehicle sail and deployed systems	3	5
Surface, undersea, and weapon vehicle materials	10	15
Surface and undersea vehicle structures	11	15
Alternate energy and power sources research and development	1	2
Vehicle vulnerability, survivability, and force protection	14	20
Active and passive acoustic signatures and silencing systems	22	60
Nonacoustic signatures and silencing	5	17
Facility operations	36	79
Totals	170	349

Effects of a Stretched Design Program on Navy Technical Resources

As described in Chapter Three, the traditional design workload at the shipyard designing a new submarine class involves a gradual increase in manning for the first two years of the design effort, then a sharp

increase in the workforce between years 2 and 6, a brief plateau in the manning at the design peak, and finally a sharp decrease over the remaining several years. The Navy's technical resources, which have technical authority over the design process and provide smart-buyer support to the acquisition community, typically follow this workload. (The involvement of NSWC's Carderock Division in test and evaluation somewhat mitigates the decrease in demand that is experienced by other design organizations late in the program.) The goal of level-loading is to have the design effort take place over a longer period of time, with a lower level of peak workload that is maintained for several years.

A level-loaded design effort could have a beneficial effect on the Navy's technical resources. A level-loaded design that could commence relatively quickly for the new SSBN class would alleviate a primary concern—the need for additional funding to retain the core submarine technical personnel at NSWC's Carderock Division. A level-loaded design effort would result in a lower volume of work and lower employment at Carderock, but there should be enough work for Carderock to maintain its technical baseline with its identified core of 170 engineers. Moreover, there is no more effective means by which to maintain engineering proficiency than work on continued, relevant submarine design projects.

The level-load design concept has some potential drawbacks. The duration of the submarine design effort, already substantial at 15 years, will be stretched even longer. The Navy will have to expect and budget for additional iterations of technology refresh cycles. Additionally, the long design lifetime will lead to increased opportunities to change requirements, which can also lead to increased costs. Finally, a stretched design lifetime could increase costs, as the program effectively must pay fixed costs for an additional four to five years.

Summary

The effect of the design gap on the Navy's technical resources varies by organization. Within NAVSEA, a mission-funded organization, the

design gap will have little impact on manning levels but will negatively affect technical-proficiency levels. In particular, the lack of opportunities to perform whole-ship-integration activities will cause some skill degradation within the current group of senior engineers and hinder the development of the next generation of senior design managers.

The impact on NSWC and NUWC, which provide the bulk of the Navy's submarine design technical and engineering talent, will be profound in the case of NSWC's Carderock Division and relatively minor in the case of NUWC. The bulk of NUWC's combat, sonar, and communication systems development is no longer tied to new submarine design, so the effect of a design gap would be marginal at NUWC. The situation within the submarine technical community at NWSC's Carderock Division is quite different. New submarine design programs provide the bulk of the funding for submarine technical work at Carderock. Current funding programs, in the absence of a new design effort, would be unable to sustain a design capability at Carderock: An additional $30 million to $35 million per year would be required to support the core group of 170 engineers.

CHAPTER NINE

Conclusions and Recommendations

The motivating concern for this research is the potential for the loss of U.S. submarine design capability, given the gap in design demand inherent in the Navy's current shipbuilding plans. We investigated the two aspects of this loss in capability—the loss of workforce capacity and the loss of critical skills—in assessing the potential for capability erosion at the shipyards, at the suppliers, and in the Navy itself.

We evaluated two shipyard workforce management strategies: (1) sustaining some number of workers in excess of those needed to meet the residual design demand during the gap and (2) letting the workforce erode and then rebuilding at such time as design work on the next class of submarines commences. We found the former to be less expensive. The number of workers to sustain depends on various assumptions. Consider a design duration similar to those for preceding classes (15 years), a workload similar to that for the *Virginia* class, and a start date for designing the next class that is consistent with current Navy ship replacement plans (2014). In that case, EB would accomplish the next design least expensively if it sustained 800 designers and engineers during the gap, and NGNN if it sustained 1,050. These numbers vary up or down by a few hundred when the workload and start date are varied over likely ranges.

The design workload could also be varied both spatially and temporally. It could be split between the two shipyards, in an effort to maintain two capabilities. This does not appear to convey an advantage, either in cost or in workforce sustained, even if it is assumed that division of the workload will cause no inefficiencies, which seems unlikely.

The workload could also be stretched out over time. For example, the 15-year effort could be stretched to 20 years and, importantly, begun early in 2009, which would eliminate most of the design gap. In that event, no extra workforce above current design work need be sustained to minimize cost (assuming all the work is done by one yard), and the cost minimum would be lower than that achievable with a 15-year design. There are some drawbacks to stretching out the design (e.g., the greater possibility of design obsolescence by the time the first of class is launched), and these must be considered in any decision regarding this option. However, there is also an important drawback to sustaining workers in excess of demand: the need to find them something to do that will allow them to maintain their skills. Several options are available, but even in combination, these may not be sufficient for skill retention equivalent to that achievable by work on a new submarine class.

While we do not address the specifics of the critical-skills problem, we break out the recommended sustained workforces by general skill categories, based on information from the shipyards regarding the breakdown of the entire design workforce. We also offer some aggregate-level observations regarding the effect of the evolution of such skills on decisions as to which to support. We identify workforce demographics, time required to gain proficiency, and supply and demand as among the factors that should be considered.

The potential problems arising from a design gap extend beyond the shipyards. Numerous submarine components are provided by vendors that must design their products. We conducted a partial survey of firms to inquire about some of the issues faced also by the shipyards (demographics, time to proficiency), as well as about issues more specific to vendors (presence of competitors, percentage of work devoted to design). We found that, while on any one dimension most firms appear likely not to encounter problems in contributing to submarine design after a gap, some appear to be potentially at risk in more than one respect.

The Navy's roles in submarine design include designing certain components and exercising responsibility for ensuring that various aspects of design are consistent with safety and performance standards.

We reviewed these roles, along with workforce structure and trends in pertinent Navy organizations, and came to a quantitative conclusion: Sufficient design expertise in the various major skill categories was unlikely to be sustained to support HM&E submarine design functions at NSWC's Carderock Division. Between $30 million and $35 million per year would be required to sustain sufficient staff in submarine design in excess of those needed during the design gap. For both the Navy and some vendors, avoiding the greater part of the design gap (e.g., by stretching out the design of the next class and starting it early) would obviate the need for concern over skill loss.

From these analyses and conclusions, we reach the following recommendations:

- Seriously consider starting the design of the next submarine class by 2009, to run 20 years, taking into account the substantial advantages and disadvantages involved.

If the 20-year-design alternative survives further evaluation, the issue of a gap in submarine design is resolved, and no further actions need be taken. If that alternative is judged too risky, we recommend the following:

- Thoroughly and critically evaluate the degree to which options such as spiral development of the *Virginia* class or design without construction will be able to substitute for new-submarine design in allowing design professionals to retain their skills.

If options to sustain design personnel in excess of demand are judged on balance to offer clear advantages over letting the workforce erode, then the Navy should take the following actions:

- Request sufficient funding to sustain excess design workforces at the shipyards large enough to permit substantial savings in time and money later.
- Taking into account trends affecting the evolution of critical skills, continue efforts to determine which shipyard skills need action to preserve them within the sustained design core.

- Conduct a comprehensive analysis of vendors to the shipyards to determine which require intervention to preserve critical skills.
- Invest $30 million to $35 million annually in the NSWC's Carderock Division submarine design workforce in excess of reimbursable demand to sustain skills that might otherwise be lost.

APPENDIX A

Workforce Simulation Model

The workforce at a design and engineering contractor is in continual flux. If demand increases, the workforce expands to meet that demand, although its response might be somewhat delayed. If the demand declines, the workforce shrinks through workforce reductions. Other changes also occur. Workers retire and leave the workforce. New workers are hired and trained as needed. Existing workers become more experienced as they apply and expand their skills. Thus, we view a design and engineering workforce as a dynamic system that primarily responds to the time-dependent demands placed on it. Its ability to respond to these demands is constrained by a number of factors, including labor availability, worker training and absorption practices, and worker productivity.

Our workforce simulation model tracks the number of workers over time segregated by:

- Skill/discipline
- Age bracket (*a*) (this is a range of ages; e.g., ages 21–25 years would be one level)
- Experience level (*p*) (the years of work experience)
- Time (*t*) (the number of time steps since the beginning of the simulation).

Counts of the number of workers are stored in a matrix in the above four dimensions. The count in each matrix element for the current time step depends on the cell values for the previous one. In other words, the number of prior workers will largely dictate the number of future

workers (subject to demand). We can generalize these relationships for a single skill as follows:

$$w_{a,p,t} = \left\{ \begin{array}{l} \rho_{a-1}^{age} \rho_{p-1}^{pro} w_{a-1,p-1,t-1} \\ +(1-\rho_{a}^{age}) \rho_{p-1}^{pro} w_{a,p-1,t-1} \\ +\rho_{a-1}^{age}(1-\rho_{p}^{pro}) w_{a-1,p,t-1} \\ +(1-\rho_{a}^{age})(1-\rho_{p}^{pro}) w_{a,p,t-1} \end{array} \right\} (1-\alpha_p) + h_{a,p,t}$$

where

$w_{a,p,t}$ = the number of workers in age bracket *a* and experience level *p* at time *t*,

α_p = the non-retirement attrition rate for experience level *p*,

ρ_a^{age} = the probability of moving to the next age bracket (*a*+1); if *a* is the last age bracket, the value is the retirement rate from that age bracket. This formulation assumes a uniform distribution of ages within each age bracket. For example, if the previous age bracket is the age range 21–25 (a range of five years) and the time interval is one year, the probability would be (1/5)/1 = 0.2 = 20 percent.

ρ_p^{pro} = the probability of promoting to the next experience level (*p*+1). As a simplification, we assumed that the probability to promote is proportional to the number of mentors available (i.e., the number of workers in the highest experience category). For example, if the mentor ratio was 1:3 and there were 15 inexperienced workers and 2 experienced ones, the promotion rate would be (2×3)/15 = 40 percent.

$h_{a,p,t}$ = the number of new hires (or workers let go if negative) into age bracket *a*, experience level *p*, and time *t*.

The first term inside the large brackets in the equation accounts for workers who both promote to the next experience level and also move to the next age bracket. The second term accounts for workers who promote but who do not move to the next age bracket. The third

term covers workers who do not promote but who move to the next age bracket. The fourth term accounts for workers who neither move to the next age bracket nor promote to the next experience level. The last term in the equation (outside the brackets) is the number of workers either terminated or hired during that time step.

Calculating the value $h_{a,p,t}$ is somewhat more involved as it is based on a number of assumptions as to how a firm might behave if faced with a workforce surplus or deficit. If there are excess workers, the model uniformly decreases the number of workers so that supply equals the demand. In practice, the actual reductions would be done based on individual evaluations. To simplify the model, we assume that experience/proficiency is directly correlated to work experience, which is not quite accurate. In practice, some fraction of the less experienced workers might be more productive/cost-effective than the more experienced ones. We do not model individual employees but rather the population of employees in the multiple dimensions we track (i.e., skill, age, experience, time). Another complicating real-life factor is that labor agreements might restrict how the reductions are handled (i.e., less experienced workers are let go instead of more experienced workers). The behavior we model reduces the workforce in a proportional way so as to not skew the age/experience distribution.

For a time step where there is net hiring, the overall number is constrained by three conditions:

- The number of new workers hired at time t does not exceed the maximum growth rate. The total number hired is the minimum of

$$g \sum_{a,p} (1-\alpha_a) h_{a,p,t-1}$$

  where g is the maximum growth rate. In other words the number of new hires cannot exceed some fraction of the number of existing workers. For example, if mentoring ratios set the maximum growth rate at 1:1 (one new worker paired with one experienced one), g would be 50 percent.
- The total number of workers is never greater than the peak demand. In other words, the peak of the demand for the design

and engineering effort is never exceeded owing to the fact that one cannot "throw bodies" at the problem to increase output. An organization or process will have some maximum number of workers it can accommodate.

- The total number of workers at time *t* does not exceed the work required at time *t*. Extra workers will not be carried in anticipation of future demand or in an attempt to accomplish work early to get ahead (i.e., the firm will not front-load the workforce). Employment levels are set based on the known demand for the time step. This constraint is based on the fact that the firm will plan not based on anticipated productivity but rather on actual planned headcounts and the work to be done. Also, this constraint reflects the fact that funding cannot be spent faster than planned or budgeted.

When adding workers, the number of new hires of a particular age and experience level is based on a distribution of new hires.

As the simulation moves forward in time, there could be points where less work is accomplished relative to what is desired. This might occur through low productivity or the inability to hire enough workers. In such cases, a backlog of work is accumulated and is applied as additional demand for the next time step.[1]

Abstract Assumptions

In order to illustrate the effects of a gap using the model, we make a number of assumptions relative to the characteristics of the workforce and demand. We simplify the presentation by modeling a single skill only in time steps of one year. We assume that a new design and engineering effort follows a trapezoidal distribution spread out over ten years and peaking at 100 workers. The notional distribution is shown in Figure A.1.

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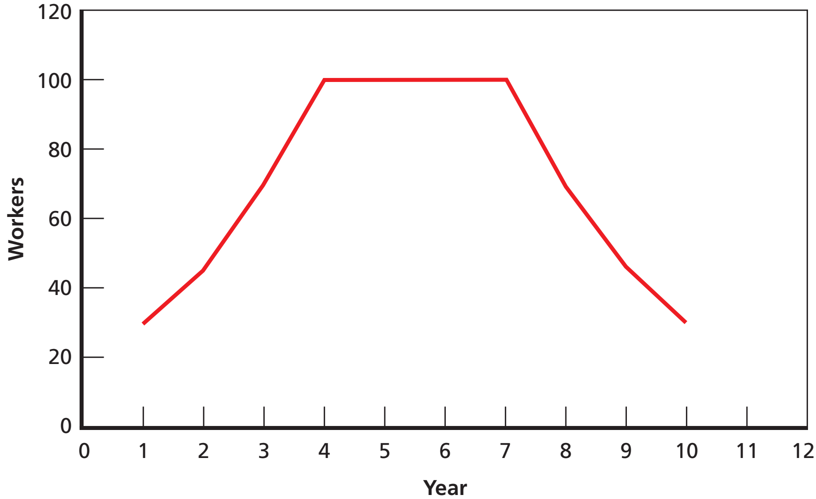
1 In such a case the number of workers could exceed the planned number of workers (i.e., additional workers are employed to work off the backlog).

Figure A.1
Notional Labor Demand for a New Design and Engineering Effort



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Other assumptions for this sample situation are as follows:

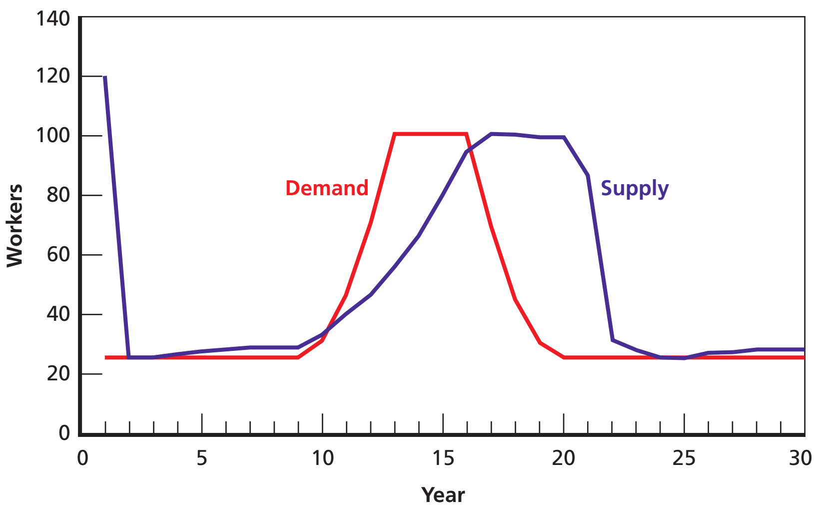
- All workers retire after age 65.
- The attrition rate for non-retiring workers is 3 percent per year, uniform across age and experience.
- The maximum hiring rate is 25 percent per year of the current employment level.
- All new workers hired are inexperienced and fall into the age category 21–25 years.
- Productivity grows steadily over eight years, starting at 50 percent at the first year and reaching 100 percent by the eighth year of experience. After the eighth year of experience, productivity remains at 100 percent.
- The initial workforce is uniformly populated with workers between ages 31 and 65, all having ten or more years of experience.
- No fixed costs are incurred to hire and train new workers.
- No termination costs are incurred.
- Indirect rates do not vary with workforce size.
- Mentoring ratios are ignored (i.e., workers always promote).

Baseline Example

Using the assumptions above, we simulate the impact of a gap by setting a minimum workforce level before the new design and engineering effort in Figure A.1. The levels are 10, 25, 75, and 100 workers (or 10 percent, 25 percent, 75 percent, and 100 percent of the peak). This minimum level will be maintained for at least nine years to let the system reach equilibrium and prior to the start of the new design (the gap). After the design effort finishes, employment is held at 25 workers for all cases. Figure A.2 shows the employment level maintained versus the demand for the case where the gap level is held at 25 workers. Supply is the simulated workforce levels and the demand is the work to be accomplished.

Notice that after the initial, sharp decline in supply (due to a layoff), employment grows slightly higher than demand during the gap years. This difference arises from the fact that new, inexperienced workers are replacing retiring workers and those lost to attrition. Since these new workers are not 100 percent efficient, more workers are needed to

Figure A.2
Employment Supply and Demand Versus Time for Baseline Example



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offset the lower productivity. Once the new effort begins, employment rises again, but it does not rise as rapidly as the demand profile because of growth rate constraints. Both supply and demand peak at 100 workers, but notice the peak for the supply occurs later (about 4 years). Two other important features to note are that (1) the area under the supply curve is larger than the demand (more expensive) and (2) supply drops to the final value later (schedule delay).

Table A.1 shows the relative cost and schedule performance as a function of the minimum employment level maintained during the gap. The values are normalized to the case where the gap level is 100 percent of the peak demand for the new design effort. For example, a value of 1.1 implies a cost 10 percent more or a schedule 10 percent longer than the case where the gap workload level was 100 percent. Not unexpectedly, the cost and schedule penalties increase as the gap workload declines. Relative cost grows uniformly over the intervals whereas schedule grows in a non-linear form. However, as the time interval of one year is coarse, there may actually be schedule index differences for the cases between 50 percent and 100 percent that we cannot resolve.

Sensitivity to Certain Growth Rate and Productivity Assumptions

Three of the more important parameters in the model are the maximum growth rate, the productivity improvement with experience, and

Table A.1
Relative Cost and Schedule Performance

Gap Workload Relative to Peak (%)	Relative Cost	Relative Schedule
10	1.20	1.7
25	1.15	1.2
50	1.09	1.0
75	1.04	1.0
100	1.00	1.0

the attrition rate. If our earlier assumptions are changed, how are the results in Table A.1 affected? Figure A.3 shows the sensitivity of the cost index to the assumed growth rate. Recall that 25 percent was our assumed growth rate maximum for the base case. As can be seen, the cost index is *insensitive* to the growth rate.

Figure A.4 shows the relative schedule index sensitivity to the assumed maximum growth rate. The growth rate assumptions have a very strong effect on schedule index. Once the maximum growth rate gets above 50 percent of the peak maximum, the schedule is relatively insensitive to the initial workload. In other words, the workforce can expand as rapidly as required for our example.

One might expect productivity improvements to have a strong influence on relative cost. New workers produce less useful work in their first few years and also reduce more experienced workers' productivity through mentoring activities. Thus, a firm with inexperienced workers must either employ additional workers to offset the productivity loss, use overtime, or fall behind schedule. All of these approaches would raise the cost of a design effort relative to a case where the workforce was fully experienced.

To examine the sensitivity of both relative schedule and cost to productivity assumptions, we make two additional such assumptions, one where new workers become fully productive in a shorter period of time and one where the workers become productive more slowly. Figure A.5 compares the three productivity assumptions.

Figure A.6 and Figure A.7 show the sensitivity in relative cost and schedule for the different productivity assumptions, respectively. As seen, productivity has a strong influence on cost and a minor influence on schedule. Not unexpectedly, slower productivity improvement equates to higher relative cost and longer relative schedules.

Finally, we explore the sensitivity of the relative cost and schedule to the attrition rate. Figure A.8 and Figure A.9 show the sensitivity of relative cost and schedule to three different attrition rate assumptions: 0 percent, 3 percent, and 6 percent. The attrition rate does indeed influence the relative schedule and cost: The greater the attrition rate, the higher the relative schedule and cost.

Figure A.3
Relative Cost Sensitivity to Assumed Growth Rate Maximum

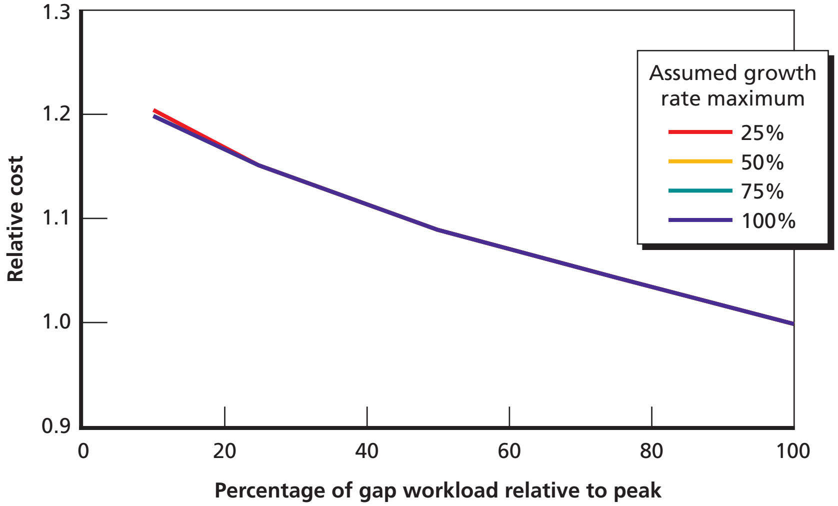

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Figure A.4
Relative Schedule Sensitivity to Assumed Growth Rate Maximum

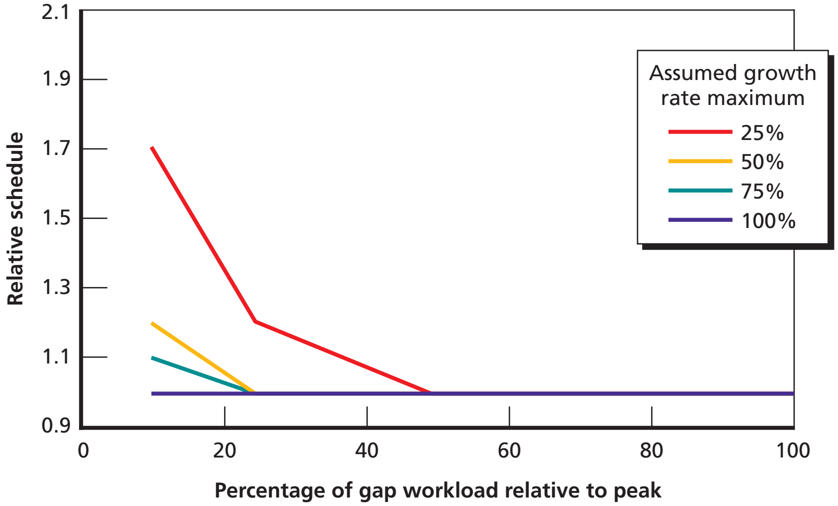

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Figure A.5
Assumed Productivity Improvement with Employment Experience

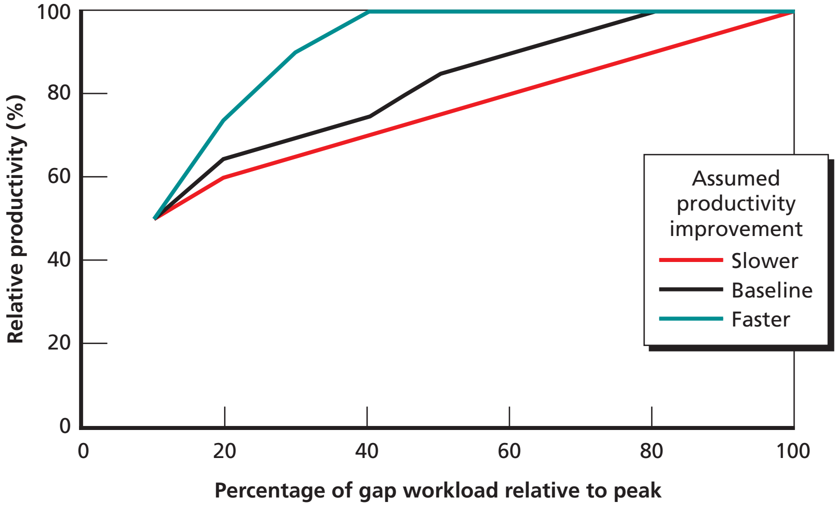

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Figure A.6
Sensitivity of Relative Cost to Productivity Improvement

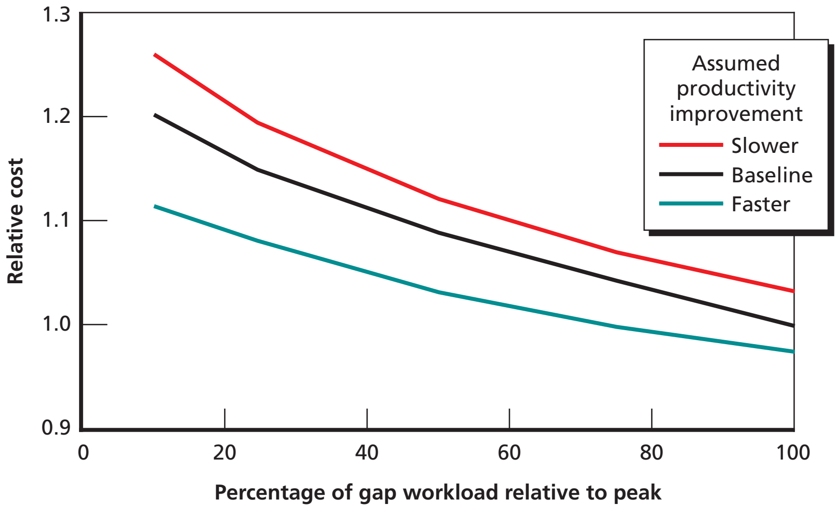

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Figure A.7
Sensitivity of Relative Schedule to Productivity Improvement

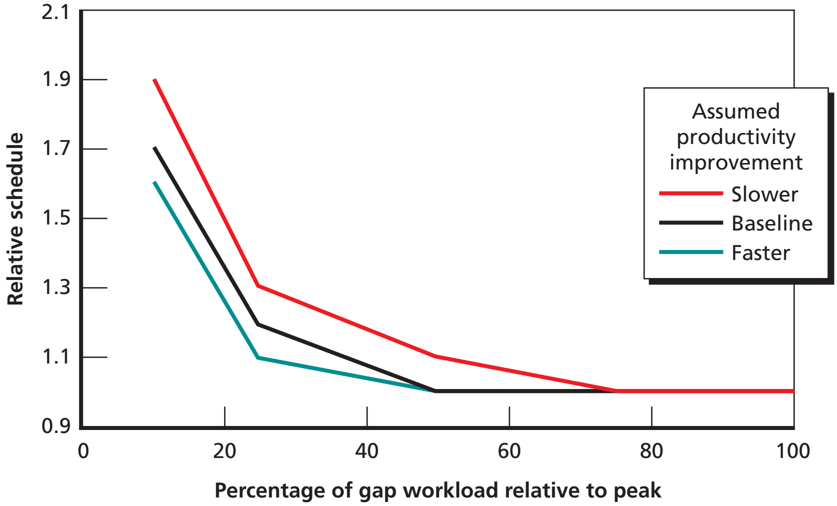

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Figure A.8
Sensitivity of Relative Cost to Attrition Rate

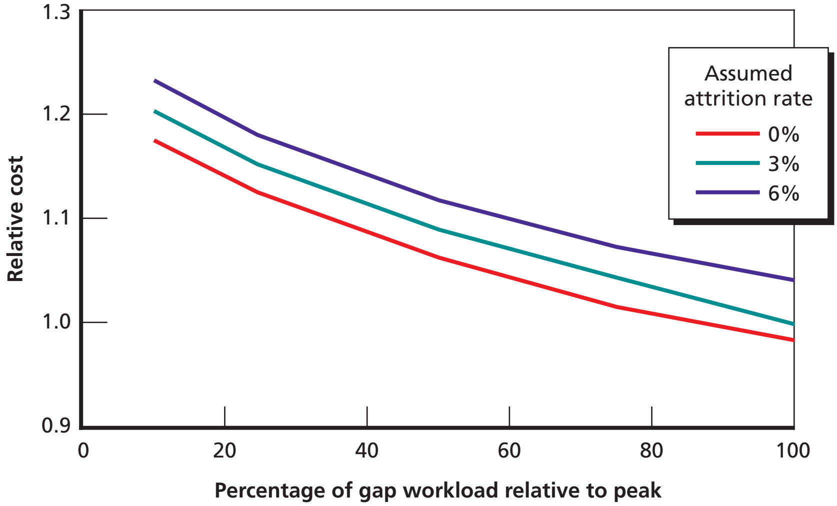

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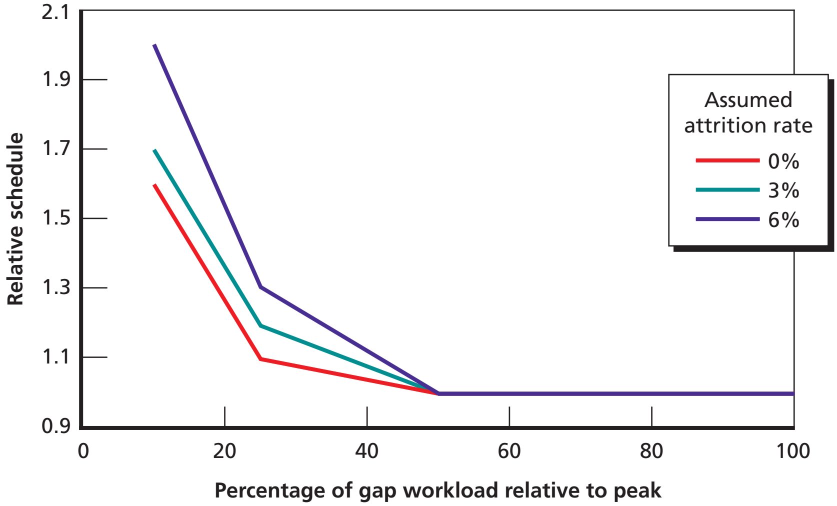
Figure A.9
Sensitivity of Relative Schedule to Attrition Rate



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Summary

Gaps in workload can be disruptive to organizations and can incur both additional costs and schedule delays when work is restarted. To quantify the effects of design gaps, we have developed a simulation model to estimate the cost and schedule implications. We observed that the workload during the gap moderates the effects on cost and schedule. The lower the workforce drops during a gap, the greater impact on cost and schedule afterward. Under our assumptions, dropping below 50 percent of the future peak workload seems to have the greatest impact on future cost and schedule. These effects are influenced by the assumptions we made. Lower productivity of new workers is one example. The longer it takes for new workers to become proficient, the greater are the effects on cost and schedule. Greater worker attrition rates have a similar effect; higher attrition rates imply greater growth in

cost and schedule. Rates at which new workers can be absorbed into an organization mainly affect schedule.

APPENDIX B

Survey Instrument for Electric Boat and Northrop Grumman Newport News

This appendix replicates the survey instrument sent to EB and NGNN requesting the data needed for our analysis.

Introduction

Throughout this survey, please provide data by specific skill category where possible. If data are not available at the specific skill level, please provide at the Engineer/Designer level. Additionally, please specify which skill categories are included in any "Other" or "Other Engineering" categories. Include information on all company design resources, not just those devoted to submarine design.

1. Please provide the average number of your company's employees in 2005.

Skill Category		2005
Designers		
	Electrical	
	Mechanical	
	Piping/Ventilation	
	Structural/Arrangements	
	Other	
Engineers		
	Acoustics/Signal Analysis	
	Combat Systems Integration	
	Electrical	
	Fluids	
	Mechanical	
	Naval Architecture	
	Planning & Production	
	Structural/Arrangements	
	Testing	
	Management	
	Engineering Support	
	Other Engineering	

2. Please provide your current workforce age distribution by skill category.

Skill Category		<21 yrs old	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	>60 yrs old
Designers											
	Electrical										
	Mechanical										
	Piping/Ventilation										
	Structural/Arrangements										
	Other										
Engineers											
	Acoustics/Signal Analysis										
	Combat Systems Integration										
	Electrical										
	Fluids										
	Mechanical										
	Naval Architecture										
	Planning & Production										
	Structural/Arrangements										
	Testing										
	Management										
	Engineering Support										
	Other Engineering										

3. Please provide the current distribution of your workforce by years of experience in the field. If information is only available for years at EB/NGNN please specify and provide this data.

Skill Category		<1 year	1 - 2 years	3-5 years	6 - 10 years	11 - 20 years	21 - 30 years	>30 years
Designers								
	Electrical							
	Mechanical							
	Piping/Ventilation							
	Structural/Arrangements							
	Other							
Engineers								
	Acoustics/Signal Analysis							
	Combat Systems Integration							
	Electrical							
	Fluids							
	Mechanical							
	Naval Architecture							
	Planning & Production							
	Structural/Arrangements							
	Testing							
	Management							
	Engineering Support							
	Other Engineering							

4. Please provide the average number of annual recruits and their attrition (voluntary departures only) by skill category over the past five years.

Skill Category		2001 to 2005 Annual Average Number Hired	Percent of Voluntary Departures in first 5 years
Designers			
	Electrical		
	Mechanical		
	Piping/Ventilation		
	Structural/Arrangements		
	Other		
Engineers			
	Acoustics/Signal Analysis		
	Combat Systems Integration		
	Electrical		
	Fluids		
	Mechanical		
	Naval Architecture		
	Planning & Production		
	Structural/Arrangements		
	Testing		
	Management		
	Engineering Support		
	Other Engineering		

5a. What is the maximum annual growth rate you could sustain as a percentage of the workforce? Does this vary by skill? If so, please provide.

5b. What constrains that rate (e.g. productivity, available recruitment pool, etc.)?

6. Please indicate the typical experience level of your new hires as a percent of those hired.

Skill Category		<1 year	1 -2 years	3-4 years	5-10 years	>10 years
Designers						
	Electrical					
	Mechanical					
	Piping/Ventilation					
	Structural/Arrangements					
	Other					
Engineers						
	Acoustics/Signal Analysis					
	Combat Systems Integration					
	Electrical					
	Fluids					
	Mechanical					
	Naval Architecture					
	Planning & Production					
	Structural/Arrangements					
	Testing					
	Management					
	Engineering Support					
	Other Engineering					

7a. From which universities do you typically recruit new engineers?

7b. What organizations or industries do experienced engineers typically come from?

7c. Please describe the typical recruitment pool for designers (e.g. certain vocational schools, grown within the organization, etc.)

8. Can you identify any existing untapped sources for potential recruitment? Furthermore, to what extent can the submarine design industry draw from other industries and how transferable are these skills?

9a. Are there particular skills or disciplines (e.g. a specific type of engineering) that are in high demand or for which recruiting is difficult? Please explain.

9b. Please indicate the number of personnel currently employed in the skills listed in Question 9a and the number of personnel with these skills that are needed for a new design.

10a. Please provide your annual training cost (any cost beyond trainee salary) per worker by experience.

	<1 year	**1 year**	**2 years**	**3 years**	**4 years**	**5 years**	**6 years**	**7 years**	**>7 years**
Designers									
Engineers									

10b. Are there any skills that have significantly higher training costs? Please describe.

11. Please indicate the relative productivity (percentage relative to the highest skilled worker) by experience and skill category. We have assumed all workers to be fully productive by 10 years, if this is not the case, please indicate.

Skill Category		<1 yr	1 yrs	2 yrs	3 yrs	4 yrs	5 yrs	6 yrs	7 yrs	8 yrs	9 yrs	10 yrs
Designers												100%
	Electrical											100%
	Mechanical											100%
	Piping/Ventilation											100%
	Structural/Arrangements											100%
	Other											100%
Engineers												100%
	Acoustics/Signal Analysis											100%
	Combat Systems Integration											100%
	Electrical											100%
	Fluids											100%
	Mechanical											100%
	Naval Architecture											100%
	Planning & Production											100%
	Structural/Arrangements											100%
	Testing											100%
	Management											100%
	Engineering Support											100%
	Other Engineering											100%

12. How many inexperienced people can an experienced designer or engineer mentor? If these vary by skill category, please provide.

13. Please provide the average age of your workers at the time of their retirement for both designers and engineers.

14. Please provide the average number of losses by skill category over the past five years *not* due to lay-offs OR retirement (e.g. voluntary departures only). What is your typical percentage of attrition *not* including retirement?

Skill Category		2001 to 2005 Average
Designers		
	Electrical	
	Mechanical	
	Piping/Ventilation	
	Structural/Arrangements	
	Other	
Engineers		
	Acoustics/Signal Analysis	
	Combat Systems Integration	
	Electrical	
	Fluids	
	Mechanical	
	Naval Architecture	
	Planning & Production	
	Structural/Arrangements	
	Testing	
	Management	
	Engineering Support	
	Other Engineering	

15. Historically, design profiles have been fairly symmetrical, with drop-off rates somewhat mirroring build-up rates. What is your maximum annual decay rate as a percentage of the workforce?

16a. Please list skills that are specific or unique to submarine design work.

16b. Please indicate the number of personnel currently employed in those skills and the number of personnel with these skills that are needed for a new design.

16c. What submarine specialties are *not* utilized in other types of ship design programs?

Historical and Future Design Plans

17. Please provide data concerning your historical and future design efforts. Please provide data starting with the Seawolf program and going as far into the future as possible. Also, please include activities such as in service support, Research and Development efforts, and any other activities that may require design and engineering resources. *Note: if there are more than 10 activities, please expand the list*

Activity	Name / Description	Start of design (month/year)	End of Design (month/year)	Delivery of product	Please list the phases of design that were participated in(concept development, prelim, etc)		
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Resources Demands

18. For *each* design activity listed on the "Historic and Future Design Plans" table (Question 17 of this form), please provide the requested information with respect to the workload demand for the shipyard (replicate this page as many times as necessary).

Activity
Name:___________________________
Type of Work:_ (New design, modification or upgrade, etc.)___________________
Number on Current and Future Production Plans Table (Question 17):__________________

	Designers					Engineers											
Year	Elec	Mech	Piping/ Vent	Structural	Other	Acoustics	Combat Sys Int	Elec	Fluids	Mech	Naval Arch	Plan/ Prod	Struct/ Arrange	Test	Manage	Eng Support	Other Eng

Understanding Workload Elasticity

19. We understand that all submarine design, engineering and management skills contribute to the completion of a submarine design. However, we are interested in understanding, at the highest level, the activities and skills that have the greatest impact to the schedule of a design effort. Can you please describe below the activities and the sequence that lie on the critical path for completing a design? What skill sets are associated with those activities?

20a. In addition, we are trying to understand the implications of “stretching” a design. If we assume the design effort is similar to the Virginia, only four years longer, how would the total manhours required differ? How would the peak manhours required differ? Please specify any assumptions being made. If possible, please provide a labor profile in number of people by skill per year for this hypothetical design effort:

	Designers					Engineers											
Year	Elec	Mech	Piping/ Vent	Structural	Other	Acoustics	Combat Sys Int	Elec	Fluids	Mech	Naval Arch	Plan/ Prod	Struct/ Arrange	Test	Manage	Eng Support	Other Eng

21. In your opinion, what would be the necessary changes required in order to minimize any inefficiencies caused by intentionally extending a design effort? How would the organization adjust to operate at this slower design rate? What variables/conditions are critical to the feasibility of such a design profile?

22a. It is well understood that using historical data to project future design profiles has certain implications. In order to better understand how a future design effort may differ from a historical design effort it is important to understand how a future design may differ. In your opinion, what new skill sets will be required 10 years from now?

22b. In your opinion, what existing skill sets will ***no longer*** be required in 10 years from now?

22c. Given that skill sets required for a design change over time, and that design tools improve over time, can you comment on how a design effort (e.g., peak and total manhours required) might differ in the future? Please explain.

23. What is the company strategy for workforce planning when demands change? When work is ramping up, does contract funding constrain the ramp up rate? When work is falling off, do union restrictions or other factors affect lay-off rates?

24a. Historically, how frequently have design systems/tools changed? What drives a change (e.g., cost, design start date, etc.)?

b. Can you please describe the development cycle for a new design tool/system?

c. What skills are critical for successful implementation of a new design process/tool?

Burden Rate Information

Definition: The term "burden" refers to overhead, general and administrative, and fee/profit costs. These costs that are proportional to the direct hours and are, typically, billed as a percentage of the direct labor hours.

25a. Please provide the average, fully burdened hourly rate for your employees by skill category in 2005 dollars.

Skill Category		**2005 Average**
Designers		
	Electrical	
	Mechanical	
	Piping/Ventilation	
	Structural/Arrangements	
	Other	
Engineers		
	Acoustics/Signal Analysis	
	Combat Systems	
	Electrical	
	Fluids	
	Mechanical	
	Naval Architecture	
	Planning & Production	
	Structural/Arrangements	
	Testing	
	Management	
	Engineering Support	
	Other Engineering	

25b. What are your standard work hours per year?

25c. Please provide in the table below how burden/overhead changes as a function of the current business base. If you have separate burden rates for different areas / skills, please provide a rate table for each area. Alternatively, please provide the Forward Price Rate Agreement for the engineering and design pool.

% Change in Business Base	Total Direct Hours	Burden / Overhead Rate (%)	Wrap rate ($/hr)
20%			
10%			
0%			
-10%			
-20%			

25d. In the above table, what assumptions have you made concerning the fixed burden costs (such as asset depreciation, rent, and facilities maintenance)? Please describe

APPENDIX C

Survey Instrument Provided to Vendors

1. Is your organization an independent company? ☐ Or a subsidiary of another company?

   If a subsidiary, please provide the name and address of your parent company.

Name and address of parent company

2. Is your organization or parent company publicly held? ☐

3. If publicly available, what are your expected total revenues for 2005? ☐ What were they in 2000? ☐

4. What percentage of your annual revenue derives from design work? Manufacturing? Servicing/repair? Other (please specify)?

5. Please provide a description of your main lines of business, providing the following information.

Description of business		Percent of revenues (last 5 years)	# of Major customers	# of Major competitors
Naval sector				
	Submarines			
	Aircraft carriers			
	Surface combatants			
	Auxiliary/commercial			
Commercial Maritime				
Other Commercial				

6. How stable are the above percentages? Where do you see them trending in the future?

7. For the components your company designs for a new class of submarines
   - What are the key disciplines involved?

   - What are the staffing levels required?

	Person days	Duration of effort (days)	Peak Staffing
Design Project Management (includes estimating, planning, program control, project management)			
Technical/ Engineering by key discipline (e.g. design, drafting/CAD, electrical, mechanical, welding, industrial, and other engineering disciplines)			
Manufacturing/ Touch Labour Supporting Design (e.g. preparing models, test rigs, etc.)			
Direct support (includes quality control, Info Technology, etc.)			

- Will there be sufficient personnel, with the right disciplines, on staff:
  - 5, 10, 15, or 20 years from now to design components for a new submarine design?

8. Please provide information on your current design workforce as indicated in the table. (Please note whether your responses are based on a yearly average or end of the year values.)

	2000	2005				Future			
	Total	Total	Under age 45	Age 45 and older	% on Submarine Work	Expected departures next five years	# hires needed within the next year	Estimated # hires needed over next five years	Ease of hiring (low, medium, high)
Design Project Management (includes estimating, planning, program control, project management)									
Technical/ Engineering by key discipline (e.g. design, drafting/CAD, electrical, mechanical, welding, industrial, and other engineering disciplines)									
Manufacturing/ Touch Labour Supporting Design (e.g. preparing models, test rigs, etc.)									
Direct support (includes quality control, Info Technology, etc.)									

9. If you have to supplement your design or engineering staff in the future to accomplish design of components for a future submarine class, how would you go about it?
    - New hires from universities? Industry?
    - Transfers from other company divisions?
    - Farm-in from engineering support companies?
    - Farm-out of certain design details?

10. How quickly could you ramp up to a design staff large enough to design components for a new class of submarines?

11. Is there a maximum rate of hiring or assimilation of new personnel into your design or engineering staff?

12. How long does it take new hires to be:
    - Trained?
    - Productive?
    - Familiar with submarine design requirements?

13. How successful have you been in hiring replacement design/engineering staff in recent years?

14. Do you anticipate any future problems in hiring design or engineering staff? Are there particular worker skills that are in high demand or for which recruiting is difficult? If so, please explain.

APPENDIX D

U.S. Navy's Technical Warrant Holders

Chapter Seven examines the Navy's roles and responsibilities in supporting submarine design efforts. One of the critical roles the Navy fulfills is that of the technical authority for its submarines. The Navy administers its technical authority through its technical warrant holder program. Technical warrant holders are chosen based on their expertise and must certify within their area of expertise that a design is safe, technically feasible, and affordable. Table D.1 presents the 172 technical warrants within NAVSEA. The technical warrants are divided into six categories. Ship design managers (SDMs) manage systems engineering efforts for their assigned platforms. Chief systems engineers (CSEs) assist SDMs in systems engineering integration of complex warfare systems into platforms. Cost engineering managers (CEMs) ensure independent cost engineering and estimating in support of Navy programs. Technical area experts (TAEs) are the Navy's experts in their assigned product technical areas. Technical process owners (TPOs) provide definition and documentation for their assigned technical processes. Depot chief engineers (CHENGs) lead and focus the technical efforts of the Navy from the waterfront and depots. Table D.1 is a snapshot of NAVSEA's technical warrant holder structure as of 2006, and lists the 172 technical warrants by the type of warrant, the title of the warrant, the NAVSEA organization granting the warrant, and the organizational code of the warrant holder.

Table D.1
Navy Technical Warrant Holders

Warrant Type	Title	Organization	Code
Ship Design Manager	T-AKE	SEA05	SEA 05D4
Ship Design Manager	DDG 51-MYP	SEA05	SEA 05D2
Ship Design Manager	DD(X)	SEA05	SEA 05D2
Ship Design Manager	LCAC	SEA05	SEA 05D4
Ship Design Manager	LPD 17	SEA05	SEA 05D3
Ship Design Manager	LHD 8	SEA05	SEA 05D3
Ship Design Manager	SSN 23	SEA05	SEA 05U5
Ship Design Manager	T-AGM(R)	SEA05	SEA 05D4
Ship Design Manager	DD(X) EDM	SEA05	SEA 05D2
Ship Design Manager	CVN 77	SEA05	SEA 05D3
Ship Design Manager	*Virginia* Class	SEA05	SEA 05U2
Ship Design Manager	LCS Flt1	SEA05	SEA 05D2
Ship Design Manager	LCS Flt0 Ship 2	SEA05	SEA 05D2
Ship Design Manager	LCS Flt0 Ship 1	SEA05	SEA 05D2
Ship Design Manager	LHA(R) Flt 0	SEA05	SEA 05D3
Ship Design Manager	MPFF	SEA05	SEA 05D4
Ship Design Manager	MPFF(F) C4I Variant	SEA05	SEA 05D4
Ship Design Manager	SSGN Submarine	SEA05	SEA 05U4
Ship Design Manager	Carrier RCOH	SEA05	SEA 05D3
Ship Design Manager	In-Service Carriers	SEA05	SEA 05N2
Ship Design Manager	In-Service Combatants	SEA05	SEA 05N2
Ship Design Manager	In-Service Submarines	SEA05	SEA 05U3
Ship Design Manager	In-Service Amphibious Ships	SEA05	SEA 05N2
Ship Design Manager	In-Service Mine Warfare Ships	SEA05	SEA 05N2
Ship Design Manager	Deep Submergence Systems	SEA05	SEA 05U1

Table D.1—Continued

Warrant Type	Title	Organization	Code
Ship Design Manager	DDG 51 Class Construction	SEA05	SEA 05D2
Ship Design Manager	ONR Ship Programs	SEA05	SEA 05D4
Ship Design Manager	Advanced Surface Ship Concepts	SEA05	SEA 05D1
Ship Design Manager	Advanced Submarine Concepts	SEA05	SEA 05U6
Ship Design Manager	CVN 21	SEA05	SEA 05DC
Ship Design Manager	Egyptian FMC	SEA05	SEA 05D4 / NSWC CD23
Ship Design Manager	Barges	SEA05	SEA 05D4
Ship Design Manager	High Speed Vessels	SEA05	SEA 05D4
Ship Design Manager	Oceanographic Ships	SEA05	SEA 05D4
Technical Area Expert	Combat Systems ISE for LPD 17 Class	SEA06	NSWC PH S20
Technical Area Expert	Combat Systems ISE for CV/CVN	SEA06	NSWC PH4Y11
Technical Area Expert	Combat Systems ISE for L Class (LHA, LHD, LSD 41/49)	SEA06	NSWC PH4Y11
Technical Area Expert	Combat Systems ISE for DDG 51 Class	SEA06	NSWC PHA01
Technical Area Expert	Combat Systems ISE for DD 963 Class	SEA06	NSWC PH4G04
Technical Area Expert	Combat Systems ISE for CG 47 Class	SEA06	NSWC PH A01
Technical Area Expert	Combat Systems ISE for FFG 7 Class	SEA06	NSWC PH4C40
Technical Area Expert	Combat Systems ISE for MCM/ MHC Class	SEA06	NSWC PC A03
Technical Area Expert	Combat and Weapons Control Systems, Submarines	SEA07	NUWC N22
Technical Area Expert	Combat and Weapons Control Systems, Surface Ships	SEA06	NSWC DD T

Table D.1—Continued

Warrant Type	Title	Organization	Code
Technical Area Expert	Submarine Training Systems	SEA03	SEA 07L1
Technical Area Expert	Surface Ship Training Systems	SEA03	SEA 03C3
Technical Area Expert	Missile Launcher Integration Submarines	SEA07	NUWC N40
Technical Area Expert	Launcher Systems, Surface Ships (except USW)	SEA06	NSWC DD G20
Technical Area Expert	Surface and Air Torpedo Launch Accessories	SEA07	NUWC K40
Technical Area Expert	Chemical & Biological Defense for Navy Warfighters	SEA05	SEA 05P5
Technical Area Expert	Unmanned Surface Vehicle Systems	SEA06	NSWC PC A03
Technical Area Expert	Ordnance Packaging, Handling, Storage and Transportation	SEA00V	NSWC IH71
Technical Area Expert	USW Launcher Systems, Payload Integration	SEA07	NUWC N40
Technical Area Expert	Submarine Sail Systems HM&E	SEA05	SEA 05Z10 / NSWC CD96
Technical Area Expert	Unmanned Underwater Vehicles Systems	SEA07	NUWC N82
Technical Area Expert	Torpedoes	SEA07	NUWC N81
Technical Area Expert	Mines	SEA06	NSWC PC A
Technical Area Expert	Electronic Warfare Systems and Decoys, Surface Ships	SEA06	NSWC CR 807
Technical Area Expert	Integrated USW	SEA07	NUWC N312
Technical Area Expert	Sonar Systems, Submarines	SEA07	NUWC N215
Technical Area Expert	Radiacs	SEA04	SEA 04LR
Technical Area Expert	USW Systems, Surface	SEA07	NUWC N312

Table D.1—Continued

Warrant Type	Title	Organization	Code
Technical Area Expert	Machinery, Climate Control Systems, Ships	SEA05	SEA 05Z9
Technical Area Expert	Machinery, Fluid Systems, Ships	SEA05	SEA 05Z9
Technical Area Expert	Machinery, Controls and Monitoring Systems, Ships	SEA05	SEA 05Z5
Technical Area Expert	Machinery, Total Ship Power/ Integrated Power Systems	SEA05	SEA 05Z3
Technical Area Expert	Machinery, Fasteners, Ships	SEA05	SEA 05Z
Technical Area Expert	Machinery, Electrical Systems, Ships	SEA05	SEA 05Z4
Technical Area Expert	Machinery, Deck and Underway Replenishment Systems	SEA05	SEA 05Z8
Technical Area Expert	Machinery, Hydraulic Systems, Submarines	SEA05	SEA 05Z6
Technical Area Expert	Machinery, Weapons Handling and Aviation Support Systems, Ships	SEA05	SEA 05Z7
Technical Area Expert	Machinery, Launcher HM&E Systems, Submarines	SEA05	SEA 05Z7
Technical Area Expert	Machinery, Propulsion and Power Systems, Nonnuclear Ships	SEA05	SEA 05Z1
Technical Area Expert	Machinery, Submarine Structural Closure, Hull Outfitting, Escape & Rescue, Special Warfare Systems	SEA05	SEA 05Z6
Technical Area Expert	Machinery, Propulsion and Power Systems, Secondary Plant of Nuclear Ships	SEA05	SEA 05Z2
Technical Area Expert	Materials, Coatings and Corrosion Control, Ships	SEA05	SEA 05M1
Technical Area Expert	Materials, Metallic; and Welding and Fabrication Processes, Ships	SEA05	SEA 05M2

Table D.1—Continued

Warrant Type	Title	Organization	Code
Technical Area Expert	Materials, Nonmetallic, Fuel and Lubricants	SEA05	SEA 05M3
Technical Area Expert	Structural Integrity, Submarines	SEA05	SEA 05P2
Technical Area Expert	Structural Integrity, Surface Ships	SEA05	SEA 05P1
Technical Area Expert	USW Ranges	SEA07	NUWC N70A
Technical Area Expert	Imaging, Electromagnetic, Electro-Optic, and Electronic Warfare Systems, Submarines	SEA07	NUWC N34
Technical Area Expert	Damage Control, Fire Fighting, Recoverability and Personnel Protection, Ships	SEA05	SEA 05P4
Technical Area Expert	Mine Countermeasures	SEA06	NSWC PC A
Technical Area Expert	Communications, Unique Systems and Nodes for On-Board Systems, Submarines	SEA07	NUWC N341
Technical Area Expert	USW Defensive Systems	SEA07	NUWC N824
Technical Area Expert	Combatant Crafts and Boats	SEA05	SEA 05D4 / NSWC CD23
Technical Area Expert	Explosive Ordnance Disposal (EOD) Technology	SEA00V	NEOD TD
Technical Area Expert	HM&E Systems Engineering, In-Service Submarines	SEA05	SEA 07T
Technical Area Expert	Environmental Systems and Materials Engineering, Ships	SEA05	SEA 05M4
Technical Area Expert	Underwater Ship Husbandry	SEA05	SEA 00C5
Technical Area Expert	Afloat Medical Programs	SEA05	SEA 05D3
Technical Area Expert	Hydrodynamics, including Propulsor, Hull, Appendage and Vehicles	SEA05	SEA 05H1

Table D.1—Continued

Warrant Type	Title	Organization	Code
Technical Area Expert	Missiles, Surface Ships	SEA06	NSWC DD G20
Technical Area Expert	Small Arms and Weapons, NAVSEA	SEA06	NSWC CR 408
Technical Area Expert	Salvage and Diving	SEA05	SEA 00C
Technical Area Expert	Radar, IR, RF and EO Sensors, NAVSEA (except submarines)	SEA06	NSWC CR 805P
Technical Area Expert	AT/FP Warfare Systems, Surface Ships	SEA06	SEA 61T
Technical Area Expert	Habitability Systems, Ships	SEA05	SEA 05Z6
Technical Area Expert	Guns, Surface Ships	SEA06	NSWC DD G30
Technical Area Expert	Dry-docks	SEA04	SEA 04XQ
Chief Systems Engineer	DD 963/FFG 7 Class Warfare Systems	SEA06	NSWC PH A21
Chief Systems Engineer	DD(X) Class Warfare Systems	SEA06	NSWC DD N05
Chief Systems Engineer	DDG 51/CG 47 Class Warfare Systems	SEA06	NSWC DD N05
Chief Systems Engineer	Submarine Warfare Systems	SEA07	SEA 07W
Chief Systems Engineer	CV/CVN-65/CVN 68-77 Class Warfare Systems	SEA06	NSWC DD N60
Chief Systems Engineer	CVN 21 Class Warfare Systems	SEA06	NSWC DD N60
Chief Systems Engineer	Amphibious and Auxiliary Ship Warfare Systems	SEA06	SEA 61R
Chief Systems Engineer	LCS Class Warfare	SEA06	NSWC DD N14
Chief Systems Engineer	Anti-Terrorism / Force Protection, Surface Ships	SEA05	SEA 05N3
Chief Systems Engineer	Joint Warfare Analysis, NAVSEA	SEA06	NSWC DD T50

Table D.1—Continued

Warrant Type	Title	Organization	Code
Chief Systems Engineer	Undersea Warfare	SEA07	NUWC N15
Chief Systems Engineer	MCM/MHC Class Warfare Systems	SEA06	NSWC PC A
Chief Systems Engineer	Topside Design, Surface Ships	SEA05	SEA 05D3
Chief Systems Engineer	Arrangements, Submarines	SEA05	SEA 05U1
Chief Systems Engineer	Force Level Warfare and Combat Systems Assessment, NAVSEA (except USW)	SEA06	NSWC CO ED
Technical Process Owner	Maintenance Process Standardization, Surface Ships	SEA04	SEA 04RP
Technical Process Owner	Maintenance Process Improvement	SEA05	SEA 05N1
Technical Process Owner	Reliability Centered Maintenance, Ships	SEA04	SEA 04RM
Technical Process Owner	Training Architecture and Standards	SEA03	SEA 03C1
Technical Process Owner	USW Vulnerability and Survivability	SEA07	NUWC N01
Technical Process Owner	Waterfront Test Engineering and Work Control Processes, Ships	SEA04	
Technical Process Owner	USW Modeling, Analysis and Assessment	SEA07	NUWC N60
Technical Process Owner	Materials, Nondestructive Testing and Evaluation, Ships	SEA05	SEA 05ME
Technical Process Owner	New Construction Surface Ship Certification	SEA05	SEA 05D2
Technical Process Owner	Arrangement Processes, Surface Ships	SEA05	SEA 05D / NSWC CD24
Technical Process Owner	Shock, Ships	SEA05	SEA 05P3
Technical Process Owner	USW Operational Assessment	SEA07	NUWC N01X

Table D.1—Continued

Warrant Type	Title	Organization	Code
Technical Process Owner	Diving System Safety Certification	SEA05	SEA 00C4
Technical Process Owner	Fleet Modernization Processes, Ships	SEA04	
Technical Process Owner	Occupational Safety and Health Requirements and Regulations, NAVSEA	SEA04	SEA 04RS
Technical Process Owner	Cost Engineering and Estimating Processes	SEA017	SEA 017C
Technical Process Owner	Metrology and Calibration	SEA04	SEA 04RME
Technical Process Owner	Human Systems Integration, Ships	SEA03	SEA 03TD
Technical Process Owner	Signatures and Survivability (Underwater), NAVSEA	SEA05	SEA 05T2
Technical Process Owner	Signatures and Susceptibility (Topside)	SEA05	SEA 05T1
Technical Process Owner	Survivability, Ships	SEA05	SEA 05P3
Technical Process Owner	Environmental Requirements and Regulations, NAVSEA	SEA04	SEA 04RE
Technical Process Owner	FORCEnet Implementation, NAVSEA	SEA06	SEA 61C
Technical Process Owner	Submarine Safety (SUBSAFE)	SEA05	SEA 05U3
Technical Process Owner	Level 1 Material and Identification Control Processes, Ships	SEA05	SEA 05U3
Technical Process Owner	Deep Submergence System Scope of Certification (DSS SOC)	SEA05	SEA 05U1
Technical Process Owner	Product Data Integration/ Exchange, Ships	SEA05	SEA 05DP
Technical Process Owner	Weight Control and Stability, Ships	SEA05	SEA 05H2

Table D.1—Continued

Warrant Type	Title	Organization	Code
Technical Process Owner	Technical Documentation Processes, NAVSEA	SEA05	SEA 05Q
Technical Process Owner	Open Architecture	SEA06	NSWC DD T
Technical Process Owner	Maintenance Process Standardization, Submarines	SEA04	SEA 04Y/05Y
Technical Process Owner	Technical Authority Processes, NAVSEA	SEA05	SEA 05CT
Technical Process Owner	EMI Control/EMC/EMP/ RADHAZ Ships	SEA05	SEA 0623
Technical Process Owner	Distant Support, Ships	SEA03	
Technical Process Owner	System Safety Processes, Ships	SEA05	SEA 05C
Technical Process Owner	Weapon Systems, Ordnance and Explosives, Safety and Security	SEA00V	NOSSA TD
Waterfront Chief Engineer	CHENG, NSY Portsmouth	SEA05	Code 240
Waterfront Chief Engineer	CHENG, NSY Norfolk	SEA05	Code 200
Waterfront Chief Engineer	CHENG, RMC Northwest	SEA05	Code 220
Waterfront Chief Engineer	CHENG, SUPSHIP Bath	SEA05	Code 200
Waterfront Chief Engineer	CHENG, Keyport Torpedo Depot	SEA07	NUWC K30
Waterfront Chief Engineer	CHENG, SUPSHIP Groton	SEA05	Code 200
Waterfront Chief Engineer	CHENG, RMC Southeast	SEA05	Code 240
Waterfront Chief Engineer	CHENG, RMC Japan	SEA05	Code 240

Table D.1—Continued

Warrant Type	Title	Organization	Code
Waterfront Chief Engineer	CHENG, RMC Southwest	SEA05	Code 200
Waterfront Chief Engineer	CHENG, SUPSHIP Newport News	SEA05	Code 201
Waterfront Chief Engineer	CHENG, RMC Mid-Atlantic	SEA05	Code 240
Waterfront Chief Engineer	CHENG, SUPSHIP Gulf Coast	SEA05	Code 200
Waterfront Chief Engineer	CHENG, RMC Hawaii	SEA05	Code 240
Cost Engineering Warrant	Industrial Planning and Analysis	SEA 017	SEA 017C
Cost Engineering Warrant	Aircraft Carriers	SEA 017	SEA 0175
Cost Engineering Warrant	Weapons Systems, and DD(X)	SEA 017	SEA 0174
Cost Engineering Warrant	Surface Combatants (except DD(X) and LCS)	SEA 017	SEA 0172
Cost Engineering Warrant	Submarines	SEA 017	SEA 0176
Cost Engineering Warrant	Amphibious, Auxiliary, and Sea Lift Ships	SEA 017	SEA 0173
Cost Engineering Warrant	Littoral and Mine Warfare, and LCS, NAVSEA	SEA 017	SEA 0177

APPENDIX E

Net Present Value Analysis

As presented in Chapter Four, the analysis of potential savings in the cost of the next new submarine design program from sustaining designers and engineers above the planned work was based on undiscounted, constant FY 2006 dollars. The fact that increased costs occur up front (i.e., more is spent now to sustain skills) while the savings accrue later (downstream cost of a less proficient workforce is partly avoided) makes it challenging to justify the benefits of the cost avoidance measures we discuss. Adopting these measures would mean that the Navy may have to forgo the opportunity to spend money on developing or producing other weapon systems or ships.

How does one evaluate the effectiveness of the strategies given the time dependence of the spending? Net present value (NPV) is a common business metric used to equate cash flows occurring at different periods; it is the result of a process known as "discounting." Underlying NPV is the principle that there is a time value for money. For example, lottery winners are typically given the choice of receiving either a lump-sum payment up front (for a value less than the award amount) or receiving periodic payment for several years that add to the full award value. The lower total value of the up-front payment reflects, in part, the difference in the time value of money (with some consideration for anticipated inflation as well).

As a more concrete example, suppose one could choose between having $100 today or $116 five years from now and that inflation is a constant 3 percent per year, meaning that the $116 five years from now is worth $100 in today's dollars. Having $100 today would be more

valuable than having it five years from now because of the *utility* in being able to spend it sooner. If, however, one could choose $127 five years from now, or $109 in today's dollars (after adjusting for assumed inflation of 3 percent), then the choice depends on whether one prefers the utility of being able to spend the money now or the 9 percent real increase of that money in five years. The submarine design skill retention question presents a similar choice; we need to assess the value of future savings.

Most NPV calculations use a fixed rate of return (or discount rate) to determine an effective investment that would be required today to produce some future revenue or expenditure. Using the previous example, the NPV of $100 (in current dollars) in five years, with a discount rate of 3 percent, is about $86. For DoD cost analyses, the Office of Management and Budget prescribes the discount rate and adjustment method.[1] In the commercial world, the discount rate is related to the cost of capital (i.e., the firm's cost to borrow money for investment).

Formally, NPV is calculated by determining the periodic cash flows of revenue and expenditure and discounting them based on the time period when they occur:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

where

t is the number of time periods since the initial investment,

C_t is the cash flow at time period t adjusted for inflation (typically, cash outflows are negative and inflows positive), and

r is the discount rate.

In this appendix, we present the results of our analysis using net present value calculations. Since our estimates are in constant FY 2006 dollars, we assume a discount rate of 3 percent.

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1 Office of Management and Budget, *Memorandum for Heads of Executive Departments and Agencies (Subject: 2007 Discount Rates for OMB Circular No. A-94)*, Circular A-94, January 2, 2007, Appendix C.

Net Present Value Calculations for the Base Case

Table E.1 shows the results of both the net present value analysis and the undiscounted analysis of the base case for EB and NGNN. The least-cost workforce to sustain is slightly less for EB (750 versus the non-discounted value of 800) but remains the same for NGNN. The lower least-cost workforce for EB results in fewer man-years to sustain in the gap (2,600 versus 3,000 for the non-discounted case) at a lower cost ($460 million versus $600 million). The percent cost savings of sustaining the least-cost number of designers and engineers relative to the "do nothing" option are less for the NPV analysis because the future savings in design costs have lower "value." Still, the NPV analysis suggests the next new design effort will cost less if additional designers and engineers are sustained during the gap compared to the "do nothing" case.

Table E.1
Discounted and Non-Discounted Analysis for the Base Case

	EB		NGNN	
Timing of new start	2014		2014	
Duration of design effort (years)	15		15	
Magnitude of design effort (million man-hours)	35		35	
	Non-NPV	**NPV**	**Non-NPV**	**NPV**
Least-cost workforce sustained	800	750	1,050	1,050
Man-years in gap	3,000	2,600	4,400	4,400
Labor cost of gap ($M)	600	460	900	750
Cost of gap plus new design for least-cost workforce ($B)	3.5	2.7	3.7	2.9
Cost of new design under "do nothing" strategy ($B)	3.9	2.8	5.8	3.9
Labor cost savings relative to "doing nothing" (cost of gap + new design) (%)	10	4	36	26

Effect of Different Design Start Dates and Workloads

The results of the discounted analysis for various start dates and design workloads are shown in Table E.2. The least-cost workforce levels to sustain are the same in the NPV analysis as in the non-discounted analysis except for two cases: EB would sustain fewer designers and engineers (600 in the discounted analysis versus 800 in the non-discounted analysis) for the 2009 design start and reduced workload, and NGNN would sustain fewer design resources (1,000 in the discounted analysis versus 1,200 in the non-discounted analysis) for the

Table E.2
Net Present Value Analysis Results for –30 Percent to +30 Percent Difference in Design Workload at Different Start Dates

	EB			NGNN		
Timing of new start	2009	2014	2018	2009	2014	2018
Least-cost workforce sustained	600–1,150	550–1,000	550–1,000	850–1,400	700–1,200	700–1,000
Man-years in gap	10–1,500	1,200–4,500	3,300–8,500	200–1,300	2,000–5,500	5,000–7,800
Discounted cost of gap ($M)	0–260	240–770	600–1,360	40–240	400–870	870–1,240
Cost of gap plus new design for least-cost workforce ($B)	1.8–3.1	1.9–3.4	2.1–3.8	1.7–3.0	2.1–3.6	2.4–4.0
Cost of new design under "do nothing" strategy ($B)	1.8–3.5	2.0–3.5	2.6–4.4	1.9–3.6	3.0–4.8	3.3–5.6
Labor cost savings relative to "doing nothing" (discounted cost of gap plus new design) (%)	0–11	3–5	14–19	11–17	25–30	27–29

NOTE: Ranges are for –30% to +30% of the *Virginia*-class design workload.

2018 design start and higher workload. In these two cases, the total man-years to sustain during the gap are also lower. Also, discounting the future stream of costs and savings reduces the cost of sustaining the workforce during the gap and, especially, the percent savings of sustaining the least-cost workforce relative to the cost of the new design effort in the "do nothing" case. The biggest reduction in savings is associated with later start dates because of the heavier discounting of savings further in the future.

Net Present Value Analysis of Stretched Design Duration

The results of the NPV analysis of a 20-year design profile are shown in Table E.3. The NPV results for the stretched design when compared to the undiscounted analysis are similar to the comparison of the 15-year design profiles—the least-cost workforce to sustain does not change much, but the cost of sustaining engineers during the gap and the cost of the future design effort are lower in the NPV analysis because of the lower value of future costs. The percent savings for a 20-year design duration compared to the 15-year least-cost case and the 15-year "do nothing" case are only slightly less for the NPV analysis compared to the non-discounted analysis.

Net Present Value Analysis for Splitting the Design Workload

The result of the net present value calculations when the design effort is split between the two shipyards is shown in Table E.4 for the 15-year design duration and in Table E.5 for the 20-year design duration. Similarly to the net present value analysis of the other cases, the least-cost workforce to sustain stays the same or decreases slightly while the cost of maintaining the workforce during the gap and the percent cost growth decrease slightly.

Table E.3
Net Present Value Analysis of Stretched Design Duration

	EB		NGNN	
Design duration (years)	20	15	20	15
Timing of start	2009	2014	2009	2014
Least-cost workforce sustained	900	750	900	1,050
Man-years in gap	240	2,600	10	4,400
Cost of gap ($M)	40	460	0	750
Cost of gap plus new design for 20-year least-cost workforce ($B)	2.3	—	2.3	—
Cost of gap plus new design for 15-year least-cost workforce ($B)	—	2.7	—	2.9
Cost of new design under 15-year "do nothing" strategy ($B)	—	2.8	—	3.9
Percent labor cost savings relative to least costly 15-year case (cost of gap plus new design)	15	—	21	—
Percent labor cost savings relative to least costly 15-year "do nothing" case (cost of gap plus new design)	18	—	41	—

Table E.4
Net Present Value Analysis for Workload Splits: 15-Year Design Duration

Workload Split (EB/NGNN)	Split Penalty (percent)	Least-Cost Workforce Sustained	Man-Years in Gap	Cost of Gap ($M)	Cost Growth Relative to Design Done Solely by EB or NGNN (%)[a]	
					EB	NGNN
50/50	0	900	1,600	330	7	0
	25	1,150	2,800	540	37	28
75/25	0	850	1,800	370	7	0
	25	1,100	3,400	630	33	24

[a] For least-cost workforce.

Table E.5
Net Present Value Analysis for Workload Splits: 20-Year Design Duration

Workload Split (EB/NGNN)	Split Penalty (percent)	Least-Cost Workforce Sustained	Man-Years in Gap	Cost of Gap ($M)	Cost Growth Relative to Design Done Solely by EB or NGNN (%)*	
					EB	NGNN
50/50	0	N/A	0	0	17	17
	25	N/A	0	0	39	39
75/25	0	N/A	0	0	17	17
	25	800	50	10	39	39

[a] For least-cost workforce.

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